

THE
STORY *of* CANE
SUGAR



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HAWAII TEXTBOOK SERIES

THE
STORY *of* CANE
SUGAR

*As told to an imaginary class
in Agriculture*



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The seal of the University of Hawaii is embossed on the left side of the page. It features a central shield with a rising sun and a mountain, surrounded by the text "UNIVERSITY OF HAWAII" and "1907".

THE STORY OF CANE SUGAR

This is published for the benefit of the young people of Hawaii who are growing up in the midst of this remarkable industry, which furnishes nearly a million tons of sugar to the world, and especially is it intended for those who are in "Smith-Hughes" classes studying the vocation of agriculture.

THE UNIVERSITY OF HAWAII.

Outline of the Story

- Chapter I—What Is Sugar? Mr. Chemist begins the story and Mr. Botanist tells more of it.
- Chapter II—Nature's Sugar Factory. Mr. Botanist tells about the sugar cane plant, how it is built by nature as a factory for the making of sugar.
- Chapter III—How the Cane Plant Makes Sugar is told by Mr. Botanist, what sugar is made of and how nature's factory works.
- Chapter IV—Growing Sugar Cane. Mr. Planter takes up the story, telling how he grows the sugar cane and cares for the immense fields.
- Chapter V—Water For the Factory. Irrigation methods are explained by Mr. Planter.
- Chapter VI—Fertility and Fertilizers. Mr. Planter is still the story teller, explaining how the soil is made more fertile for the sugar cane.
- Chapter VII—Varieties of Sugar Cane. Mr. Botanist again takes up the story, telling of the different varieties of sugar cane, the merits of each and how new varieties are created.
- Chapter VIII—Insect Enemies of Sugar Cane. Some of the troubles that beset the cane growers are described by Mr. Entomologist.
- Chapter IX—More Troubles in the Factory. Diseases and soil troubles are described by Mr. Botanist.
- Chapter X—Harvest Time. How the cane is harvested is told by Mr. Planter.
- Chapter XI—The Sugar Mill. Extracting the sugar from nature's factory is described by Mr. Superintendent who runs the big mill.
- Chapter XII—Raw Sugar to White Sugar. The work of the big sugar refinery is described by the same story teller.
- Chapter XIII—Some History and Geography. The story goes far back to the time when men first made sugar, and a glimpse is had of world geography.
- Chapter XIV—Sugar of Many Kinds. While cane sugar is the most important, there are other kinds of sugar which the story includes.
- Chapter XV—The Small Planter. There are good opportunities in the sugar industry for young men of limited means but of unlimited zeal and determination.

Introduction

The producing of food is one of the most important things in the world, and sugar is one of the very important foods, needed by the human body to maintain health. Therefore, the sugar industry is very properly considered as one of the most necessary of the world's great industries, and Hawaii has a very prominent part in it. To be connected with this industry in Hawaii is something anybody can be proud of, for it has a good future and a great history.

There is much that is interesting and worth knowing in this industry, how the sugar cane plant grows, how it makes sugar out of air and water, how our great mills have been evolved in the brains of man, how our crop of sugar is carried to millions of dinner tables.

There is a need in the industry for many new recruits who have learned something about the work in their school days, and many of the boys and girls now in school must do their part when they grow up, to keep this great industry going.

This is not a complete story of sugar, but only a part. Some other parts of the story you, who study this in school, will be able to fill in by watching the work on a plantation, by visiting the mill, and by learning something about the history and evolution of the sugar plantation nearest to you. A little resourcefulness will enable you to prepare supplementary stories and gather facts and figures about the production of sugar, and prepare pictures and graphic illustrations.

Pictures and narratives by the pupils do much to arouse a greater interest than merely the reading of these lessons. It is hoped that no teacher will deaden this subject by reducing it to the hum-drum of memorizing and reciting certain facts and figures by the pupils. Where the "Story of Sugar" is being enacted daily all around us, it should be possible to make this study an intensely interesting part of the pupil's daily work.

A Sugar Cane Library

There are many books and bulletins on the growing of sugar cane and the manufacture of sugar, and every school can have at least a small collection of these available for the use of the pupils. The Experiment Station of the H. S. P. A. has published a large number of excellent bulletins on sugar and is therefore able to give some good help in this, and the Sugar Factors Co. in Honolulu is glad to supply pamphlets and descriptive matter about the big refinery at Crockett, California, which is owned by the plantations in Hawaii.

The following books are recommended:

Noel Deerr—Cane Sugar, Revised Edition. Publisher, Norman Rodger, London.

Quintus—The Cultivation of Sugar Cane in Java. Publisher, Norman Rodger, London.

Geerligs—The World's Cane Sugar Industry. Publisher, Norman Rodger, London.

Surface—The Story of Sugar. Publisher, D. Appleton & Co., New York.

Maxwell—Economic Aspects of Cane Sugar Production. Publisher, Norman Rodger, London.

Yearbook of the U. S. Department of Agriculture, 1923 (pages 151-229 deal with the subject of sugar). This book may be obtained by writing to the Delegate from Hawaii, Washington, D. C.

The following pamphlets and bulletins should be obtained by every school studying this subject:

Homesteading in Hawaii. A pamphlet prepared by Governor Wallace R. Farrington and published by the Honolulu Star-Bulletin, 1928.

The Story of Sugar in Hawaii. An exceedingly interesting booklet prepared and published by the Hawaiian Sugar Planters' Association, Honolulu. The development of the sugar industry in Hawaii is told briefly, with a sketch of the part played by the various pioneers who helped to establish it. Well illustrated.

Sugar Cane in Hawaii. University of Hawaii, Agric. Studies No. 2.

A Sugar Cane Farm. University of Hawaii, Agric. Studies No. 7.

A Graphic Story of Sugar. University of Hawaii, Agric. Studies No. 8. This is a valuable pamphlet, giving many graphs and tables of sugar production throughout the world.

Irrigation of Sugar Cane in Hawaii, by Wm. P. Alexander.

A bulletin issued by the Experiment Station of the H. S. P. A.

If available, the following will be very useful in the study of sugar cane:

Proceedings of the Annual Meetings of the Hawaiian Sugar Planters' Association.

The Hawaiian Planters' Record.

International Sugar Journal (published in London).

How The Story Grew

This "Story of Cane Sugar" has been several years taking its present form. At first it was a series of stories told orally to children in Ewa School, by several men, some of whom were connected with the University of Hawaii and others with the Experiment Station of the H. S. P. A. and with Ewa Plantation. Later, these stories were brought together in written form and related to each other, and mimeographed copies were sent to many of the schools throughout the Territory. After the schools had used this "Story" for two years, it was completely rewritten and printed as a loose-leaf text book, and after three years it was again revised and issued in its present form. We gratefully acknowledge indebtedness for the assistance of the Director and staff of the Experiment Station of the Hawaiian Sugar Planters' Association, the Manager of Ewa Plantation, the specialists of the Department of Public Instruction and the University Faculty members who have aided in developing this story to its present form.

DAVID L. CRAWFORD.

October, 1928.

CHAPTER I

WHAT IS SUGAR?

Our agriculture class was making a map of the world to show where some of our common foods come from. The most important food crops, explained the Teacher, are cattle and other meat animals, the cereals (wheat, rice, corn, oats, etc.) and the sugar-yielding plants.

What stories these things could tell if only they could talk. Stories of great cattle ranges and exciting round-ups and other adventures, stories of tremendous wheat ranches in Argentina, Russia, Australia, Canada or perhaps northern United States; of rice fields and interesting people of Java and the Orient; of rustling corn fields in Kansas; but perhaps the most interesting of all the stories would be told by the cube of sugar, if it could talk to the geography class. It would be a story begun under tropical skies in broad plantations and continued through great, noisy mills and then a long sea voyage and another great mill and finally the cube of sugar would be started on its final trip to your dinner table.

"Do you know what sugar is?" asked the Teacher. Of course, we knew—something sweet and good to eat, sometimes white and sometimes brown, sometimes solid and hard and sometimes sticky and runny. But that was not enough, there is much more to the answer than that. Some friends of the Teacher were invited to tell the geography class the whole story of sugar. First came Mr. Chemist, who knew what sugar is made of, for he knows what nearly everything is made of.

Sugar, says Mr. Chemist, is made of three things, not one of which by itself is sweet, but when put together in just the right way they turn into a sweet substance which we call sugar. The names of these three things are carbon, oxygen and hydrogen.

Carbon is what coal, charcoal, soot and lampblack are made of. Usually it is black, except in diamonds, where it is crystal clear. By itself it is not good to eat, but in sugar this black stuff becomes a white, sweet substance that is good to eat, when it is combined properly with those two other things.

Oxygen by itself is a gas, being part of the air we breathe continually, but we find it here as a regular part of a solid material. It has a sharp taste something like an acid, but in sugar it enters into a combination to make a sweet taste instead of the acid sharpness.

Hydrogen is another gas, sometimes used for balloons, but its most common occurrence is in combination with oxygen to form water.

So Mr. Chemist begins the story, how these three things that he calls elements change their appearance and taste when they get together and become the stuff we call sugar. There are several different kinds of sugar,* as malt sugar and milk sugar and fruit sugar, and, also, there are various kinds of sweet substances a good deal like sugar, as glucose, syrups, and others. Cane sugar, beet sugar and maple sugar are practically the same, and this kind of sugar he calls sucrose. Differences in flavor are caused by the presence of substances other than the three described above, carbon, oxygen and hydrogen. Maple sugar, for example, usually has some impurities in it that give a very pleasing flavor.

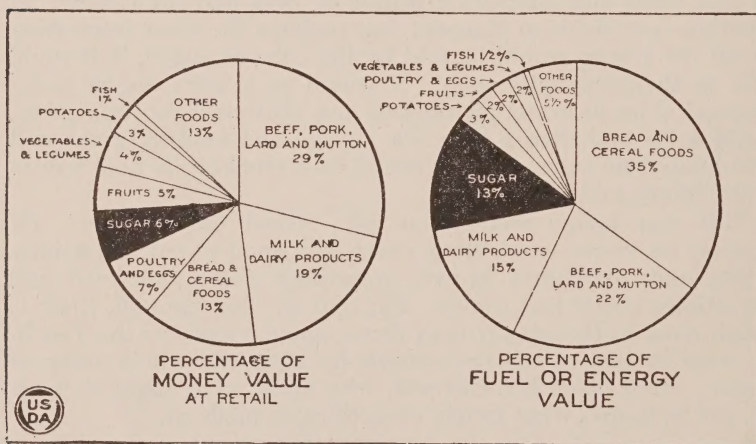


FIG. 1.—This diagram shows the relationship of sugar to other foods. The figure on the right shows that about 13 percent of the total energy of foods eaten by the American people is furnished by sugar, but the other figure shows that sugar costs less than most other foods, for only 6 percent of the total food cost is spent for sweets. (U. S. Department of Agriculture, Yearbook, 1923).

All these different kinds of sugars are made of the same three elements, but the proportions are different. It is like taking three sets of building blocks and putting them together in different ways to make toy houses and structures of wholly different appearance. The blocks of each set are the same, but what they make may be very different. Because these different kinds

* See Chapter XIV.

of sugars are made out of carbon, hydrogen and oxygen they are commonly called by a long and difficult word, *carbohydrate*. Starch, also, which is made of the same things in a different arrangement is a carbohydrate.

So we say to Mr. Chemist, how do you put together these three elements that are like building blocks to make sugar? Do you do this in your laboratory? Do you measure out so much carbon, so much oxygen and the right amount of hydrogen and then shake them up together to make sugar, or starch, or whatever you may want? And he replies that it is very difficult to make sugar in the laboratory, and very expensive, and never done commercially. If this were not so we would not need all our sugar mills and plantations, for we would simply make our sugar in a laboratory out of these three elements, for they are very abundant and common. He tells us that we must depend on plants to properly combine these "building blocks" to make sugar and starch.

So Mr. Botanist, who knows all about plants, is invited to continue the story where Mr. Chemist left off. He tells us that nearly all kinds of plants make sugar, for it is one of the chief foods of plants. That is surprising. We had thought of sugar as a food that people like to eat, and had not stopped to think that plants might use it, too. In fact, we had not thought that plants eat any of the same foods that we use.

How Plants Eat

How do plants eat sugar? Mr. Botanist explains that sugar in a liquid form makes up a large part of the sap of plants—the fluid that moves up and down in plants something like our blood does in us, except that plants do not have a heart to pump the fluid as we do. This sap flows into all parts of the plant body, just as our blood does in our body, and each little part of the plant takes what it needs from this food-stream as it slowly flows along, and uses it for growth and repairing wastes, in just the same way that our bodies use the food that is carried by the blood. Some of it is turned into protoplasm—the living substance—and helps the plant to grow larger. And that is how the plant uses sugar, for animals and plants are very much the same when it comes to consuming food. We do not easily realize this because there is so much difference in the first processes of eating, for of course plants do not chew nor swallow their food nor digest it in a stomach as we do, but beyond the digestion stage the processes are about the same.

Now we think of ourselves as being smarter than plants and yet they can make sugar and we cannot. For that reason we are very dependent on the plant kingdom for sugar and starch

foods. Even when we eat beef and pork and fish and other members of the animal kingdom, we are still dependent on the plant kingdom, for those animals have to have plants to eat. So we find that the whole animal kingdom is dependent on the plant kingdom and would quickly die off if there were no plants.

But Mr. Botanist has not told us **how** the plants make sugar and our surprise becomes greater when he says that they make it simply from air and water and sunshine. How remarkable! It's a long story, he says, but it is very interesting. There is time now for only a short account of this story but later he will tell us more.

Sugar from Air and Water

By a sort of breathing process through tiny pores, so the story runs, the plant takes air into its leaves, while through the roots a continuous supply of water is absorbed and carried up to the leaves. These are the raw materials from which the plant makes sugar.

Air is really a mixture of several kinds of gases, one of which is carbon-dioxide. To us this gas is poisonous, and it is fortunate, therefore, that there is only a very small amount of it in the ordinary air which we breathe. To the plants, however, it is very useful, for it is this part of the air which helps to form sugar. In the leaves this carbon-dioxide gas is united with water in such a way as to make a sugary liquid, provided there is sunshine on the leaves. It sounds simple, but we cannot do the same thing in our chemical laboratories. We put carbon-dioxide into water and make soda-pop, but the sweetness and flavor of soda-pop have to be added in the form of sugar and flavoring extract. Without these latter, the soda-pop would not be much good.

The reason why plants are able to make sugar out of carbon-dioxide and water is that they have in their leaves an abundance of tiny green particles which in the presence of sunlight have the special power of doing this work. These green particles are so abundant that they give a green color to the leaves of plants. The name **chlorophyll** is given to this green substance, for the name means "green leaf." Without sunlight the chlorophyll particles are unable to do their work and, therefore, when night brings darkness the plants all stop their sugar making. Sunlight furnishes energy or power to carry the process through. Plants that are kept in darkness soon die because they cannot make food for themselves and therefore become starved.

Some plants, like toadstools and mushrooms, are not green but pale white. Such plants have none of the green substance, chlorophyll, and therefore are not able to make sugars and

starch for themselves. That is why these plants are so often parasites, robbing their food from others because they cannot make their own.

After the sugary fluid is made in the leaves it is mixed with the sap and flows to other parts of the plant so that every living cell unit may be properly fed, and some extra sugar is made for the plant to use during the night and on very cloudy days when there is not enough sunlight power to keep the chlorophyll working.

The Savings Bank

In most plants the extra sugar is turned into starch which keeps better in storage and in that form is stored away in roots or stems, as we put extra money in the savings bank. Then when the bank account has to be drawn upon, the starch is changed back into sugar and dissolved in the sap and carried away.

Sugar cane, however, is not like these other plants, for it keeps its bank account in the form of sugar instead of starch, and therefore men can "rob" the bank and get the sugar. This is why the sugar cane plant is so valuable to us, for it yields to us large quantities of the sugar which it has stored up for the "rainy day."

To change the sugary liquid of the cane stalk into the solid white crystals which we know as sugar is another story, Mr. Botanist declares, and we will save that for another time. Of course we are familiar with the fact that sugar easily dissolves in water and although we can no longer see it we know it is there for we can taste it. It is simply reversing the process to change the liquid into solid crystals of sugar.

And now we have one more thing to consider about sugar. We have been talking about sugary fluids and dissolved sugar, but we are familiar with sugar as a hard, solid substance of tiny granules. What is the difference between these? It is explained to us that sugar is a solid, made up of tiny crystals of a regular shape, but when these crystals are put in water they disintegrate and disappear from view, and we no longer see the substance but we can taste it.

In this new form it must still be regarded as sugar, even though it has taken on a different form. It is in the liquid state that we find sugar in the cane stalk and the beet and the maple tree, and bees store it in the same form in their hives. By boiling the water away, we can restore the sweet fluid to its solid crystalline condition—and that is the work of our great sugar mills.



FIG. 2.—*Sugar Crystals.* Sucrose sugar made from cane juice forms into crystals shaped like these. The small brown spots among the crystals are tiny drops of molasses. (H. S. P. A. Exp. Sta.)

Words to Remember

Carbohydrate—A substance composed of carbon, hydrogen and oxygen in various proportions; sugar and starch are the best examples.

Carbon—A chemical element composing most of the solid part of all living bodies, both vegetable and animal; coal is what remains from ancient plants.

Carbon-dioxide—A gas composed of two elements, carbon and oxygen, formed by burning wood or coal and breathed out by animals; it comprises about 4 parts in 10,000 of ordinary air; it is used in carbonated drinks to give a sharp “tang” and a sparkle.

Chlorophyll—Tiny, microscopic, green particles of living matter within plant cells which have the ability of combining carbon-dioxide and water to form sugar.

Dissolve—The process of a solid substance becoming a liquid.

Element—A substance which cannot be separated or broken up into substances different from itself, as carbon, copper, gold, iron, lead, mercury, oxygen, etc.

Glucose—A thick, sticky, sweet syrup made from starchy materials and used by bakers and confectioners.

Hydrogen—A chemical element which by itself is in gaseous form but most commonly occurs in combination with oxygen to form water.

Oxygen—A very important gas, comprising about one-fifth of the atmosphere, and essential to all living things for maintenance of life.

Protoplasm—The living substance of all plants and animals, a fluid which holds the life principle.

Sap—The liquid which moves about in plants and contains the various food substances dissolved in water.

Sucrose—Sugar which will readily form into crystals when freed from the water in which it is dissolved; cane and beet sugar are examples.

CHAPTER II

NATURE'S SUGAR FACTORY

A Study of the Sugar Cane Plant

Plants are really sugar factories, Mr. Botanist explains, when he is again with our Class continuing the story of sugar. The leaves correspond to the factory buildings and the tiny granules of green chlorophyll are the machines, and there are millions of them. Instead of having electric motors to furnish power for its machine, this factory gets its power from the sun, for the rays of sunlight, coming like electricity transmitted by wireless, enable these little green machines to work busily and with no noise or fuss whatever, from daylight to nightfall. They need no attendants to watch or guide them, for each seems to know its part in the factory's work and does it without being told.

Every factory, of course, must have a continuous supply of the raw products which it uses for the manufacture of its finished product, and this sugar factory requires air and water. Instead of having a system of railroads with puffing trains to haul in the raw products, this factory has a very intricate system of tiny pipe-lines through which air is drawn in from the atmosphere and water carried up from the soil, meeting at the little green machines as efficiently as though numerous puffing engines were guiding the stream of traffic.

A good factory must, also, have a proper arrangement for taking the finished product away from each machine as fast as it is made, for otherwise it would pile up and hinder the work of the machine. This sugar factory is very well arranged in this regard, for there is another system of pipe-lines so extensive that all the sugary fluid turned out by the green machines is taken in and carried away, so that the machines are never hindered in their work but continue steadily along throughout the day.

Such is the factory which nature has made in every green plant. We are especially interested, however, in one particular sugar factory which makes cane sugar. This is the sugar cane plant which grows only in the tropical and subtropical parts of the earth's surface, for it cannot endure very cold

weather. A closer study of the sugar cane plant will, therefore, be important before we go any further in our story of sugar.

A Giant Grass—The sugar cane plant is really a gigantic grass, for it is a member of a great assemblage of plants which the botanists call "grasses." This includes not only the common grasses of the field and roadside, but also rice, wheat, barley, oats, corn and other cultivated **cereal** crops and such plants as elephant grass, sugar and even bamboo.

All of these plants—and there are thousands of different kinds or species in this grass family—are more or less alike in several respects. All, for instance, have jointed stems or stalks, and the stems are hard outside and either hollow or pithy inside. The leaves, too, have a certain similarity, not only in shape but in arrangement. The root system, also, has some features of resemblance throughout the great family, but it is in the flowers and seeds that the closest similarity exists. The flowers of grasses are simple in structure and inconspicuous, and depend almost wholly on the wind for pollination. There are no petals or showy parts.

The Stem or Stalk

(Note: If possible, have a sugar cane plant before you for study, getting the entire plant—root, stalk and leaves.)

Hard and Jointed—The sugar cane stalk is hard and smooth on the outside. It is often covered with a fine, powdery dust or waxy substance known as **bloom**, which gives pretty colors to some varieties in addition to the fixed colors in the stem itself.

At intervals of two to five or more inches you find a joint in the stem. These are called **nodes** and the spaces between the joints or rings are known as **internodes**.

At the lower end of the stalk, where the leaves have fallen off and left the nodes and internodes bare, examine one of the nodes carefully and observe the following things:

Buds or Eyes—The most prominent thing is the bud or **eye** on each node. This spherical or pointed, wart-like swelling is really a very important part of the stalk when it comes to planting new fields, for this is the part that grows into a new plant. Observe the arrangement of these buds, one on each node and on the opposite side of the stalk from the one next below or above.

The bud or eye is really a young stem that started to grow out as a branch from the main stem and then stopped growing and became dormant, like the tiny embryo plant in the

bean seed which is tucked away between the two big seed leaves (cotyledons).

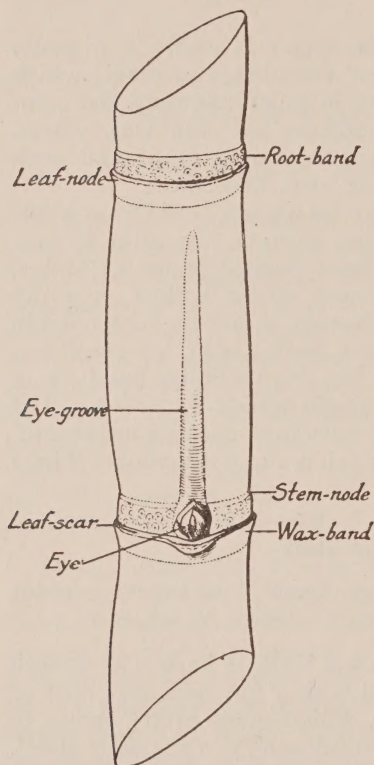


FIG. 3.—Portions of Cane Stalk showing one complete internode and two nodes, with a bud or eye on the lower node. Above each node is a root-band from which the roots grow out. When such a stick as this is planted in the soil the first roots to grow out are from the larger circles at the bottom of each root-band. The leaf is attached at the point indicated in the figure as "leaf-scar." (H. S. P. A. Exp. Sta.)

With a sharp knife cut off one of the buds low down on the stem (for these are larger) and then cut this bud in two, lengthwise. You see that it is enclosed by two or three dry layers of small leaves and inside of these are quite a number of tiny green leaves tucked away in compact layers. Peel these off carefully and count them. The inner leaves are thinner and more delicate, while in the center you find several very slender leaves which are only a little developed. Even the stem is visible at the base of the bud.

Above each bud there is usually found a groove in the internode, which appears to have been provided by Nature as a help to the young plant when the bud begins to grow out beyond its resting or dormant condition.

The Node—Now study carefully the node, or joint, itself. First, you see a raised ring, often with a fragment of a leaf

still there, showing that this raised ring serves as the point of attachment for the leaf. Carefully strip off the lowest leaf and notice how it was attached. This raised portion is usually called the **leaf scar**.

Above the leaf scar, on the upper portion of each node, you find a lot of small round warts which become less distinct as you look at nodes higher up the stalk. Look on the lowest nodes and you may find that these little warts have grown out into roots. This tells us that all these warts are kind of embryonic roots, something like the buds are embryo stems. These clusters or rows of embryonic roots are called **root-bands**.

This is Nature's provision for propagating the sugar cane plant, for we shall see later that seeds are not much used for this purpose. A piece of stalk, with one or several buds and the embryonic roots, is the usual means of planting new fields, and therefore we commonly call these pieces of stalk by the somewhat misleading name of **seed**.

Wax-band—Below the root-band and below the scar or ring where the leaf was attached is a more or less depressed area quite thickly covered with the powdery bloom referred to above. This is often called the wax-band or bloom-band, and is part of the node, though it grades off into the internode without a visible margin.

It may be interesting to make a drawing of the stalk held in such a position as to show both rows of buds (in profile) on opposite sides of the stem, and to show the different features we have examined thus far. If you have colored pencils or crayons, show the color areas of the stalk, for that is not only interesting but also important in recognizing different varieties or kinds of sugar cane. Be careful to match as closely as possible the color of the stalk.

Internodes—Are the joints or internodes all uniform in length or do they vary? What about the thickness? It will be interesting to measure each internode, beginning at the lower end of the stalk and going to the tip end, measuring the length between the raised rings where the leaves were attached. Also measure with a string or cloth tape line the circumference of each internode at the middle and see how much variation there is from base to top.

Keep a record of all these measurements on a special record sheet which provides five vertical columns, one for the internode number beginning with number one at the lower end of the stalk, the second column being for the length of the internodes, the third column for the circumference, the fourth for the length of the leaf attached to each node, and the fifth col-

umn for remarks or general notes about each unit of the stem.

Strip off one leaf at a time as you work toward the top end of the stalk, measuring the length of the leaf and joint and recording the figures before going to the next higher joint. In the next part of this story you will need to have the lengths of the leaves, so it is easier to take these measurements now. In this way your record will be more accurate and complete.

When you get up near the tip end you find that the joints are very short and by careful observation you will find quite a number of extremely short joints with the leaves small and only partially formed. This is the most actively growing region and the stem is soft and tender, requiring careful handling to avoid breaking.

To see if we really understand what we have been seeing in this wonderful sugar factory Mr. Botanist now proposes some questions.

Question 1. Which reaches its full length first, the joint (internode) or the leaf attached to it? The answer to this is in the record of measurements. Note where the leaf lengths and joint lengths begin to fall distinctly below the average of the lower full-grown ones.

Question 2. Where does the stalk grow? It is to answer this interesting question that we measured the joints. One of the characteristics about the grass family and the palm trees and lily family of plants is that the stalk grows to a certain size and thickness and then grows no more except at the upper end. That is, the lower part of the stalk reaches its full growth and becomes no larger, while the upper end is still growing larger and longer. Now, that is not like the other plants. Mango trees, and other common trees, have their trunk and branches all the time growing larger and thicker as long as they live, old trees often having immense trunks.

Of course, the best way to measure the amount of growth that takes place in a sugar cane stalk would be to record the lengths of the joints of a growing stalk on a certain day and then allow it to grow for a week or several weeks or months and then measure the same joints again. This will be a good field experiment.

However, there is a quicker way of getting this information. If we examine the record of joint measurements we find that the first ten or fifteen joints are more or less uniform in length, except for some variations which we will discuss later (in question 3), and beyond a certain point the joints become

shorter and shorter. That may be taken to indicate that all the joints of more or less uniform length are through growing and will grow no larger or longer, while the joints at the upper end of the stalk are still growing. According to this, what proportion of a cane stalk is actively growing and what proportion is not (having finished its growth)?

Question 3. Why are some full-grown joints, or internodes, shorter than others? The record of measurements shows that the full-grown joints are not uniform in length. To know the causes of these differences we would have to go back into the history of the cane plant. A certain joint was getting its growth when the conditions were excellent—plenty of water, plenty of fertilizer and plant food in the soil, abundant sunshine, nice warm weather, and very few weeds nearby to rob food and water from the sugar cane plant. So the cane plant grew luxuriantly and the joint which was then at the chief growing position grew long and healthy, and now several months later we find it full grown and longer than its fellows.

Another joint, near the big, long one, is short. Perhaps when its growth was under way the weather was colder, with less sunshine, or perhaps there was a shortage of water, or possibly there was not enough plant food in the soil because weeds were allowed to grow freely, or perhaps some kind of insect pest or disease was sapping out the strength of the plant. At any rate, we know from the shortness of the joint that there was some kind of unfavorable condition at the time that joint was getting its growth.

In other words, the joints of the sugar cane plant tell something of the story of past events and conditions as they affected the plant, just as the growth-rings in a tree stump tell the story of the tree's past life.

One who has a little imagination could now write a story about the past life of a sugar cane plant as recorded in the length and thickness of the internodes, illustrating the story with a drawing of the stalk showing the different internodes.

Question 4. How often is a new joint formed? The best way of getting an answer to this is to mark the date with indelible ink (India ink is good) on the highest exposed **ligule** of the leaf. The ligule is that part of the leaf where the blade joins the sheath (the part of the leaf that encloses the stem). Perhaps after five to ten days you will note that another ligule is visible above the one you had marked. Place a date on this new ligule and continue dating every ligule of a new leaf that makes its appearance. You will soon have an interesting record of how often new joints are formed.

Inside the Stalk—Now, to see something of the inside of this sugar factory, Mr. Botanist takes his sharp knife and cuts through the stalk, cutting across between two nodes, with the cut as clean and straight as possible. Using his pocket magnifying glass we see that the cut end is somewhat spongy with many tiny pipes or tubes, for the system of pipe lines to carry water to the leaves and to carry sugar away from the leaves runs through the entire length of the stalk.

Now he takes two joints and splits them lengthwise through the middle so that the hard node itself is cut in two. Notice the inside appearance of the node. It is a sort of partition, extending through the stem and gradually merging with the pulpy tissue on each side. If we split bamboo or grass stems we find a series of partitions (nodes) quite similar to what is in the cane stalk, but the center of the internodes of grass may be hollow, while in sugar cane it is spongy.

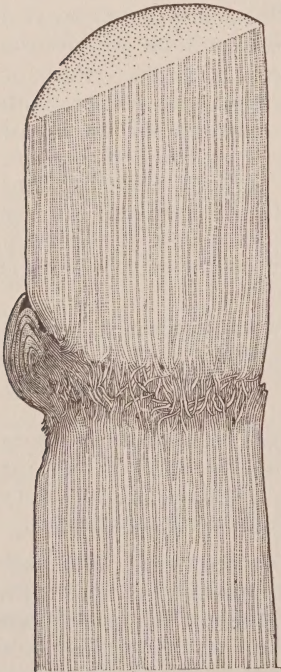


FIG. 4.—Stalk of Sugar Cane cut lengthwise through a node and eye, showing the bundles of fibres which in reality are tiny tubes through which water and sap are carried. The node is a hard partition through the stalk but the fibrous tubes extend through the hard wall.

The eye (on the left) is cut lengthwise and its structure is well shown, for it is made of several layers which really are the beginnings of several future leaves when the eye will grow into a new stalk. (H. S. P. A. Exp. Sta.)

What the Stalk Does—The stalk, or stem, does three important things for the cane plant. First, it holds the leaves and displays them in such positions that each leaf is able to get some sunlight and air and thus make food, as we shall see when we study the leaves.

Second, the stalk carries water up from the roots and supplies the leaves with water from the ground and also the chemicals dissolved in it, which we call plant foods.

Third, it is a storage place for surplus food (sugar) made by the leaves and held for some future time when it may be needed by the plant. This is the savings account which is saved up for the "rainy day," and the stalk is the savings bank.

The Leaves

The leaves of a plant are the actual factories in which sugar is made out of the raw materials, air and water. Because sunlight furnishes the power for these leafy factories, the leaves must be so arranged as to be able to absorb as much sunlight as they need. For this reason they are usually broad and thin and flat, so that there will be an extensive surface for catching the sunlight. Also, the leaves must be arranged so that one will not shade another too much. Notice the arrangement of leaves on any plant and see how little interference there is among leaves in getting sunlight. Notice the arrangement of sugar cane leaves, on alternate sides of the stalk and several inches between the leaves on a side.

Two Parts of the Leaf—The cane leaf has two distinct parts when full grown, the sheath and the blade. The sheath is usually about a foot long and more or less completely surrounds the stalk, remaining in that position until the leaf is old and about ready to fall off.

The blade is three or four times as long as the sheath. The division line between sheath and blade is a thickened portion, called ligule, at which point there is a slight break between blade and sheath, making a sort of ear-like flap on each side. These ears have tufts of hairs on them, and the hairs are so characteristically arranged that different varieties of sugar cane may be identified by examining the tufts.

Leaf Growth—The leaf gets its full growth before the internode to which it is attached is fully grown, thus providing the plant with more leaf surface and increasing the extent of its factory. By the time the leaf is unfolded and ready for work it has attained its full growth, but the internode to which it is attached is still growing. Notice on how many internodes above the full grown ones we find full grown leaves. The upper joints of the stalk are soft and tender and a great deal of care is required to successfully remove the leaf sheath from the internode, but it can be done by carefully cutting through the leaf sheath at its base. The internodes to which the upper leaves are attached are very short, small and tender.

Observe that the sheath on the uppermost expanded leaf is not as long in proportion to its blade as on the older leaves below it. This shows that the blade is the first part of the leaf to get its full growth, which is a wise arrangement because it is the part that must first begin to work. The sheath can grow while the blade is at work making sugar.

Now very carefully take out the roll of unexpanded leaves at the top of the stalk and unroll it. Unroll one leaf and you find another one inside. Observe that the first one unrolled is about as long and wide as the full grown and expanded leaves, except that the sheath is shorter. It is, of course, thinner and more delicate and would not be mature for several days to come, but it seems to have its full length and width. On this first unrolled leaf the division between blade and sheath is very indistinct, but one can see it by looking carefully.

Now unroll the second leaf. It is not as long and wide as the first. It apparently is still growing. The sheath (scarcely distinguishable) is very short in proportion to the full grown leaves. How many leaves can you find in the roll? The

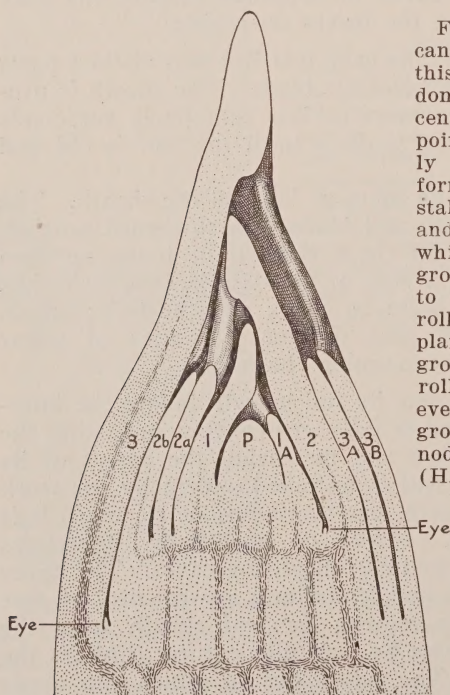


FIG. 5.—The tip end of a sugar cane stalk looks something like this, but is smaller. The little dome (p) in the middle is the center of growth or "growing point," with cells that are rapidly dividing and enlarging to form new leaves and add to the stalk. The parts marked 1, 2, and 3 are rudimentary leaves which have grown out from the growing point. These continue to grow within the spindle or roll of leaves at the top of the plant, but there is no more growth of a leaf after it has unrolled from the spindle. For every leaf that is formed by the growing point, a node and internode of the stalk is started. (H. S. P. A. Exp. Sta.)

inner ones are very tender and easily broken. Unroll them with the utmost care.

The Growing Point—Each of these small leaves inside the roll has a tiny internode to which it is attached, for what looks like a roll made up entirely of tender leaves is really the growing end of the stalk with a lot of young leaves around it. This is the growing part of the sugar cane plant.

Leaf Veins—You have observed that the sugar cane leaf has a thickened “rib” along the central line. This is called the **midrib** and is a canal system for carrying water and sap through the leaf, as well as to give strength and stiffness to the leaf to hold it in a horizontal position.

The thin portion on each side of the midrib has many parallel lines or threads. These are the **veins** which are secondary canals or pipe-lines to assist the midrib in the transportation of water and sap to all portions of the leaf.

Now examine leaves of other plants and notice the arrangement of these veins. In the hibiscus, beans and most plants with leaves of that shape you find a midrib with several branch veins and each of these branching and re-branching to make a net-work of tiny veins. In grasses, palms and lilies the leaf veins are like those in the sugar cane, forming long parallel lines on each side of the midrib. By cutting crosswise through a full grown leaf we can see the relative thickness of midrib and blade.

If we should examine a fragment or slice of the leaf under a microscope, we would find it to be a spongy mass of tiny cells

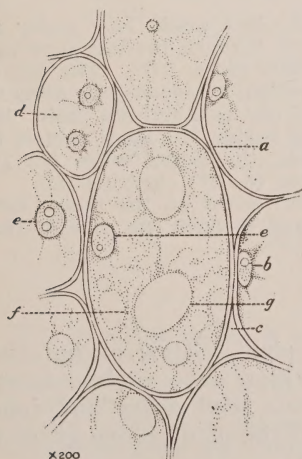


FIG. 6.—Plant cells, greatly enlarged. Each cell is surrounded by a thin wall, and contains a network of protoplasm (the living substance), indicated by the letter “f.” The life-center of the cell is the nucleus (“e”). When the cell divides into two in the growth process, the nucleus first divides itself (as indicated by “d”). In addition to protoplasm and nucleus, each cell contains some water and sap. (H. S. P. A. Exp. Sta.)

with many tubes (veins) running everywhere like a pipe-line system. This is shown well in the pictures which represent these cells very greatly enlarged under a powerful microscope. The cells near the surface of the leaf contain many of the green chlorophyll particles which we have called the machines that make the sugar. This gives the leaf its green color, but sometimes a disease causes the destruction of these green particles and then the leaf turns yellow in the diseased spots and we say the plant is suffering from "yellows," or mosaic disease.

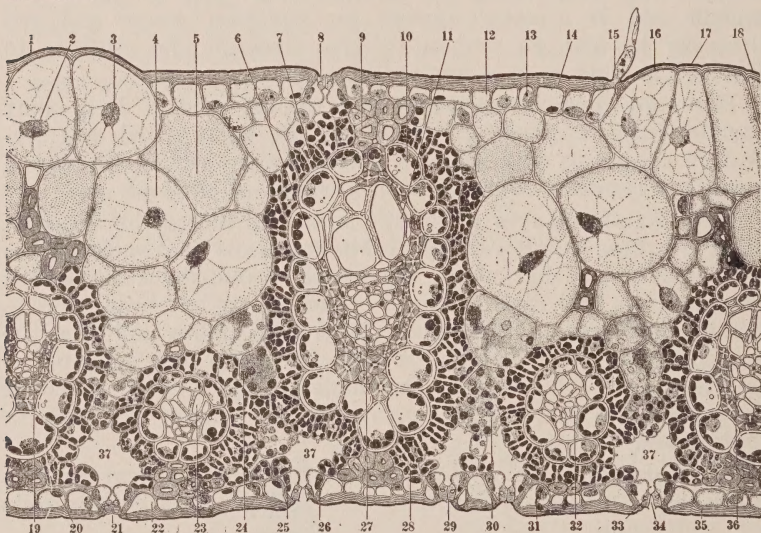


FIG. 7.—This is the way a sugar cane leaf would look under a powerful microscope. This is a cross-section through the leaf showing the cells many hundred times larger than actual size. The large groups of cells in the center of the illustration, surrounded by numerous black dots, would appear to the naked eye as a delicate "vein" in the leaf, as would also the smaller groups beside it. Each vein is a bundle of tubes and cells of several kinds, the larger tubes (as 11 above) carrying water and the smaller ones (as 27) carrying sap.

Air is taken into the leaf through tiny pores on the under surface (see 21 and 34) and passes around and through the cells of the leaf. (H. S. P. A. Exp. Sta.)

The Roots

The roots do two things for the plant. They anchor the plant in the ground so that it cannot blow away or be washed out or knocked down. Also, the roots send water and food materials from the soil to the parts of the plant above ground. These are two very important things.

The root system of the sugar cane plant consists of two parts, the feeding roots and the root-stalks. The root-stalks are really continuations of the stem or stalk which we have already studied, with its nodes and internodes and buds. The feeding roots are small, fibrous projections which grow out from the root band at each node of the stalk, as already observed above.

If we carefully dig up an entire sugar cane plant and wash the dirt from the roots, we may then see the entire root system with its abundant feeding roots and the larger root-stalks and the buds or eyes growing up to form new stalks.

The feeding roots are continually growing and pushing forward into new ground to get the food supplies which are there. Water is absorbed through the walls of these tiny roots, and there are some food elements dissolved in the soil water, and

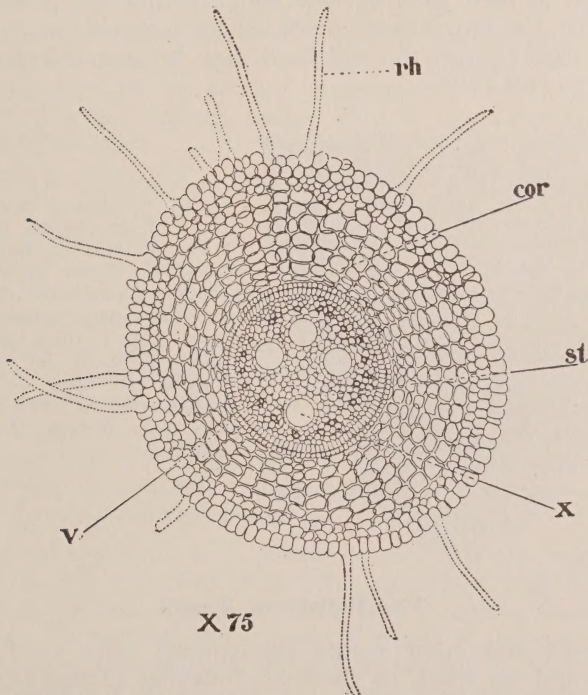


FIG. 8.—Cross-section of root-tip, greatly enlarged. The four tubes in the central cylinder ("x") are for carrying water from the soil to the leaves. The outer portion ("cor") is called the cortex and protects the central cylinder. The projections from the edge ("rh") are root-hairs which grow out among the tiny grains of soil and absorb water and dissolved chemicals and pass these fluids into the root and finally to the tubes in the center. (Illustration by H. S. P. A. Exp. Sta.)

these go along with the water when it travels upward through the roots and root-stalks to the stem and leaves above ground.

Ratoons—Like all grass plants, sugar cane sends out new stalks from its underground root system and this is usually called **ratooning** or **stooling out** or **tillering**. On each joint of the root-stalk we find a bud or eye just as on the stalk above ground. When conditions permit, some of these buds grow out and push up through the ground until they reach the surface and then grow into leaf-bearing stalks. As the cane plant grows older the number of these stalks will increase, a single plant having six to twelve or sometimes more.

When the stalks are cut off at the surface of the ground the root-stalk sends up a number of new shoots, which we speak of as **ratooning**. In this way these plants are almost perpetual in their growth, new stalks taking the place of old ones when the latter have completed their service or have been cut off. Of course, the soil food may become exhausted and then the plant fails.

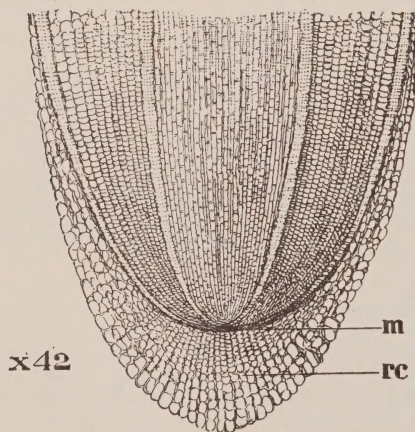


FIG. 9.—The Tip of Sugar Cane Root looks like this when it is enlarged several hundred times by a microscope. At the tip end there is a "root-cap" made of tough cells. This enables the root to push forward as it grows longer, crowding the soil particles aside to make room for the root. (H. S. P. A. Exp. Sta.)

The Flower or Tassel

Hibiscus and other plants are popular with us for their flowers and we speak of these as flowering plants, but we do not think of grasses and sugar cane as being flowering plants. Grasses do have flowers, nevertheless. They are not very showy and never have bright colors, but the flowers are present. On the corn plant when it is about full grown we see at the top of it the tassel coming out, which is composed of bunches or clusters of small flowers.

On sugar cane at certain seasons of the year, usually November or December, we see a great whitish plume or tassel on top of the plant; that is the flower cluster. It is made up of a great many little flowers, each of which consists of two parts. One part makes the seed and another produces a powdery substance called **pollen**. This pollen must be transferred to the other part of the flower in order to have the seeds develop; otherwise the seed will never mature. This transfer is ordinarily accomplished in grasses by means of the wind, while in the plants with showy flowers the transfer is made by insects. The pollen powder is very fine and light and can easily be carried about by the wind.

The Seed—When the pollen gets to the seed-forming part of the flower, certain changes take place and a seed develops with a tiny young plant within it. Sugar cane, however, very seldom grows from seeds in the field, for the seeds are very delicate and the young seedling plants are easily killed. A few seeds are developed, however, in many tassels and it is possible to obtain seedling plants by placing some mature tassels on boxes of moist soil, and taking proper care to keep the seed bed moist and protected.

When it is desired to obtain sugar cane seeds of known parentage, the pollen must be transferred by hand from a certain plant to another, and some sort of protection against other pollen must be provided, for otherwise some would be pretty apt to be blown in by the wind. This is very easily done at the Experiment Station by an ingenious method recently developed. Stalks of cane with the tassel just coming out are cut off and brought into the laboratory and placed in jars containing dilute **sulfurous acid**. This prolongs the life of the cut stalks for several weeks, allowing the tassels to develop fully as they would in the field. In this way, cross-pollination can be very easily manipulated, while in the field it requires a large amount of rather difficult work.

For school experiments in growing seedlings, take some mature tassels and lay them on a little box filled with fine soil. Keep the soil moist. The seeds will drop from the tassels and germinate. To prevent the growth of weeds in the seed boxes, it is a good thing to sterilize the soil by heating it, or steaming it or by pouring a lot of boiling hot water on the soil to heat it throughout.

Words to Remember

Bloom—Waxy powder on the surface of some fruits and on the stems of sugar cane.

Bud—The small, rudimentary beginning of a stem, leaf or flower.

Embryo—The rudimentary beginning of a new plant or animal, as in a seed or an egg.

Eye—Same as a bud, in this story.

Internode—A joint or section of sugar cane stalk between two nodes or rings.

Leaf-blade—The main part of the leaf, broad and flat.

Leaf-sheath—The lower portion of the leaf surrounding the stem.

Ligule—A small, ear-like flap of the leaf at the division line between blade and sheath.

Midrib—The thick rib along the center line of the leaf.

Node—A partition through the stem, visible on the outside as a raised ring or ridge around the stem.

Pollen—The fine powder produced in flowers, representing the male sex in the formation of seeds.

Pollination—The transfer of pollen to the seed-forming part of a flower.

Ratoon—A secondary growth springing from the underground portion of the old plant.

Root-stalk—The main portion of the root system, really a continuation of the stem or stalk.

Veins—The delicate lines in a leaf, being the tube lines which carry the sap and water.

CHAPTER III

HOW THE CANE PLANT MAKES SUGAR

Perhaps, says Mr. Botanist, we can imagine ourselves tiny enough to go into the sugar factory we have been describing and watch the machines at work. How small we would have to become to do this may be realized when we know that the cells in which the green particles of chlorophyll are packed are so tiny that 4,000 of them placed side by side would together be only one inch long. And in each of these cells there are many chlorophyll particles, indicating that these little green machines are indeed very tiny.

Each of the cells has a thin wall around its outside and on the inside it is filled with protoplasm and other fluids and sometimes air bubbles. The protoplasm is the actual life of the cell and is like thin jelly streaming around within the cell.

The chlorophyll granules are intimately associated with the protoplasm of the cell and are thereby able to do their important work. The green coloring in these tiny granules seems to be of very vital importance, for if it fades out or disappears for any reason the making of sugar stops. The appearance of these chlorophyll machines is very commonplace, merely little round particles—but the work they do is not at all commonplace, for if Mr. Chemist were to attempt the same work he would require a lot of very complicated apparatus in a laboratory.

The Power-house—The sun is a great power house, for although it is millions of miles away from the earth, it sheds upon us its rays of light and heat which furnish this old earth of ours pretty nearly all of the heat that it has. Without this the earth would be a frozen mass and no life would be possible on it. To the sun's heat also may be traced the cause of our winds and ocean currents, for by the unequal heating of certain spots of the atmosphere or of the ocean, moving currents result which develop into very extensive movements. The trade winds, so beneficial to us here, and such ocean currents as the Gulf Stream in the Atlantic Ocean are examples of these movements.

To the growing plant sunlight is a great necessity, for it is the sunlight falling gently upon the leaves which furnishes the necessary energy for the wonderful processes of food making which are going on inside those leaves.

The Raw Materials—Air and water are the raw materials from which sugar is made in the cane leaf.

The air forms a layer around the earth perhaps as much as 300 miles in thickness, but it is not the same all the way through, for it becomes thinner or more rare the farther we go upward from the earth. It is estimated that one-half of all the air is within $3\frac{1}{2}$ miles of sea level. Enough air for twilight phenomena exists up to about 40 miles; clouds have been seen as high as 50 miles; the aurora borealis runs up from 40 to 125 miles; meteors shine from 150 to nearly 200 miles up, and certain phenomena of lunar eclipses indicate a thickness of atmosphere of at least 200 miles and perhaps more.

Near the earth the air has a buoyant effect, holding up light objects as a boat floats in water; but if one were to go up from the earth this buoyant effect would be found rapidly diminishing. Beyond a certain point in the atmosphere an airplane finds so little buoyancy that it cannot go higher, although a lighter object such as a balloon would rise considerably higher.

Air is made up of at least five constituent elements, some of these being present in large proportions and others in very small proportions, as follows:

Nitrogen.....	77.50	parts in 100
Oxygen	20.64	“ “ “
Argon	1.00	“ “ “
Carbon dioxide	.04	“ “ “
Water vapor	.82	“ “ “

These constituent parts are not always found in just these proportions, for we know even without chemical analysis that air seems different to us in different spots. We sometimes complain about the air in a room full of people being “heavy,” meaning that it has a depressing effect upon us, or makes us sleepy. Now if we were to have Mr. Chemist analyze that air, he probably would find the proportions of the constituent parts quite different from the figures given above, the carbon dioxide being more abundant and the oxygen less so. Again, if we walk around the crater of Kilauea when the volcano is active, we are apt to find that the air is not uniform, sometimes seeming normal and in other spots distinctly otherwise because of the addition of other kinds of gases in the air, such as sulphur fumes.

Carbon Dioxide—For the making of sugar in the leaf only one element of the air listed above is used—the smallest factor of all—carbon dioxide. It looks very unimportant in the list above, only four parts in 10,000 of air, and yet none of the elements of air are any more important, because out of this small part of the air practically all of the world's supply of sugar and starch is made, to say nothing of lumber, fuel wood, coal, cotton clothing and many other things.

It seems strange, at first thought, that nature has not provided a larger amount of this important constituent of the air, for it means that the leaves of plants must work over a lot of air to get a small amount of the carbon dioxide.

But when we learn that carbon dioxide is poisonous for animals (including humans) if too much is breathed in we no longer wonder at its scarcity for about all we can stand without harmful effects is 4 or 5 parts in 10,000.

This small supply of carbon dioxide in the atmosphere we might easily imagine would be used up quickly when we think of the large number of plants transforming it into sugar and starch, but there is a circulation of this gas through regular cycles of manufacture and decomposition which keeps the proportion of carbon dioxide about the same all the time. The circulation is like this: The plants take in carbon dioxide from the air and change it into sugar. This sugar is extracted in the mill, refined and sent to some other part of the world where it is consumed as human food and by the processes of digestion and assimilation it becomes human tissue and then body activities cause a breaking down of these tissues and carbon dioxide is given off as a by-product, and is breathed out of the person's lungs into the atmosphere. So the carbon dioxide eventually returns into the atmosphere, having gone through several changes of form—sugar, human tissue, etc.

The carbon dioxide which was taken in by the sugar cane plant and made into sugar in Hawaii may be returned to the atmosphere in Europe in a Frenchman's breath. But the continual movement of the air currents in the long run tends to distribute and equalize the carbon dioxide throughout the earth.

There are other sources of carbon dioxide too, such as factories, volcanoes, fires of all kinds, where combustion is taking place.

Plants Breathe—To be used in making sugar the carbon dioxide of the air must, of course, go into the cells where the

granules of green chlorophyll are. That requires some kind of arrangement for the air to pass in and out of the leaves—a sort of breathing process, such as we carry on in our lungs. There are no lungs, of course, in the sugar cane leaf, but nevertheless there is a kind of a breathing process, the air passing in through a lot of tiny mouths (called **stomata**) on the under side of the leaf. A sugar cane leaf has over 20,000 of these tiny mouths.

Inside the leaf the air moves around between the loosely arranged cells and enters the cells themselves through their delicate walls. Although there are no muscles to expand and contract and thereby force air in and out of the leaf, nevertheless there is a definite movement of air in and out through the little mouths. We may call this breathing, for it resembles somewhat our own breathing process. As the air passes around and through the cells where the green granules of chlorophyll are, the carbon dioxide part of the air is absorbed and used immediately in making sugar by being combined chemically with water.

Where the Water Comes From—The water used in this sugar making process comes up from the ground through the roots and stalk and the midrib of the leaf. There is a great deal of water in the leaf, in and around the cell—in fact, the green leaf is about four-fifths water and one-fifth solid substance.

There is a continual “stream” of water coming up from the soil through the plant, because from the leaf surface there is a continual evaporation, the water turning into vapor and passing out of the stomata, the little mouths, along with the outgoing air. In other words there is a “stream” of water passing through the plant, starting from the ground and going out at the leaves, and the chlorophyll, or green cells, are like tiny islands in this stream taking in as much water as they need as it moves slowly along.

To make one pound of sugar the cane plant has to take up over 60 gallons of water from the soil and pass it along by the little green islands (cells). Think of the amount of water that has to pass through an acre of sugar cane plants!

The Storehouse—The leaves make sugar to be used as food in all parts of the plant, and as fast as it is made in the green cells of the leaves it moves out and is carried along in a slowly moving stream of sap, which is another name for the liquid food of plants containing sugar and nitrogenous substances and various minerals in solution.

We have already seen that sugar can be made only in daylight hours when there is sunlight to furnish energy, but the

plant needs food all day and all night. That means that extra supplies of sugar must be made by the leaves and stored up for those times when food is needed and cannot be made in the leaves, that is, at night and on very cloudy and rainy days and in the old age of the plant when there is less vigor.

The storehouse for the extra sugar is in the stalks, where this surplus is held until needed. There is a gradually increasing accumulation of stored-up sugar in the stalks as the plant grows older until it reaches old age; then there is a decreasing amount because the surplus is being used up. Therefore, to harvest sugar cane for our mills it is desirable to cut the stalks when they have plenty of sugar stored up inside and before the supply begins to dwindle.

Experiments

We suggest here some simple experiments which can be done in the class room to illustrate some of the points brought out in preceding pages concerning the making of sugar and starch in plants.

1. How Water Moves Up Through the Stalk—By coloring the water that goes up through the stalk you can see how far and how fast it goes and where it travels. The experiment may be set up by the teacher several hours or a day previous to the study period, or it may be set up by the class one day and studied the next day.

Directions—Fill a jar or large tumbler half full of water and pour in a little red ink to give the water good color. Now, cut off a stalk of sugar cane above the roots and place this in the red ink fluid and set it away in a corner where it will not be disturbed.

Next day, take the stalk out of the red water and cut across it at several points well above where it stood in the water. Note how the red has moved up through the stalk. Cut off thin slices of the stalk and hold them to the light, noting the red streaks. These are the tubes through which water travels. How far up the stem has the red ink left its mark? Do you find any red in the leaf veins when you hold a leaf to the light? Describe the experiment and its results.

2. Evaporation of Water from Leaves (Transpiration)—That water passes out of the leaves by evaporation or transpiration can be easily shown by placing some fresh leaves in a tightly closed jar. Observe the moisture that collects on the inside of the jar during the next few hours.

3. **Importance of Sunlight**—Place a green plant in the dark by turning a box or barrel over it or put a potted plant in a dark closet. Notice how the absence of light affects the color of the plant.

4. If you have access to a compound microscope, see if you can observe the green granules of chlorophyll by macerating a bit of leaf and examining the fragments under the microscope.

CHAPTER IV

GROWING SUGAR CANE

By this time the Class had become much interested in the story of sugar as told by Mr. Botanist and wanted to know more about this wonderful factory in which nature makes sugar out of air and water with the help of sunshine. How do they grow the sugar cane plant? How do they cultivate it? How do they protect it from pests and diseases? How do they fertilize it? How do they harvest the cane? These and many other questions were put to the Teacher and to answer them it was decided to have a continuation of the story of sugar told by Mr. Planter, who for many years had been growing sugar cane and making sugar to sell.

First of all the conditions have to be right for the sugar cane plant. So Mr. Planter's story begins. A warm and even climate with plenty of sunshine and ample water at hand, either as rainfall or in streams, springs or wells. The soil must be good and fertile, but of course fertilizers will have to be added. The land must lie favorably for being worked, not too steep or too uneven. Hawaii has a great deal of excellent land for sugar cane and some remarkably large yields have been harvested from these lands, in excess of the best yields anywhere else in the whole world. This, however, is not because the land is naturally richer or more fertile but because the best scientific knowledge has been applied by the people who grow sugar cane in Hawaii.

Preparation of the Soil—The ground is plowed to a depth of about one and a half to two feet before planting the sugar cane, for deep plowing makes it possible for the roots to grow better and this makes a large and successful plant. Deep plowing requires a powerful machine and very commonly in Hawaii the "Fowler Steam Plowing Outfit" is used. This consists of two steam engines mounted on wheels and placed on opposite sides of the field which is to be plowed, each engine having a revolving drum mounted securely below the body (see the accompanying picture). By means of a steel cable which winds up and unwinds on these revolving drums a large, specially constructed reversible plow is drawn back and forth across the field, one engine drawing in the cable with the plow attached as the other releases it. When a strip is plowed the

engines advance a few feet and plow another strip, until the whole field is plowed.

Large caterpillar tractors are also used extensively for deep plowing, especially on the islands of Hawaii and Kauai, but the greatest use of these is in furrowing for planting the seed after the deep plowing is done, and in hauling cane to the mill.

The next process after plowing in the preparation of the soil, is making the furrows in which the cane is to be planted. These are generally spaced five feet apart. In regions where no irrigation is necessary, the furrows (cane rows) are made in straight lines across the fields, regardless of ups and downs, but in irrigated sections the rows must follow the contour lines so that the irrigation water will run down the rows, and thus make irrigation possible. This work is done by specially constructed furrowing plows drawn by tractors or mules, and in most cases it is necessary to clean out and improve the furrow with hoes before planting the cane. This means that a good deal of hand work is required.

Planting the "Seed"—The "seed" pieces (sticks of cane with several eyes or buds) are placed in the furrows and covered with about three inches of earth, to allow them to strike root and grow. On irrigated plantations, the first application of water is at the planting time, usually right after the seed has been covered up. The usual method of planting is to scatter the seed sticks by hand, a man walking down each furrow carrying a bag of seed and dropping the sticks as he goes. Behind him come the men who place the sticks at proper intervals and cover them with earth.

A planting machine is used in some cases which reduces the cost of planting very greatly. This machine makes furrows, drops the seed sticks into the furrows at proper intervals and then fills the furrows and covers the seed, all in one operation.

Seed Cane—The best seed cane is that which comes from the upper part of the cane stalk, and when planting is being done at the same time that another field is being harvested, top seed is usually available. One reason for its being better is that it germinates more quickly and more uniformly, and secondly, it contains less sugar, which makes the top of the cane stalk less costly in sugar loss. If the seed sticks are pretty old they are soaked in water for a day or more before planting, as this greatly hastens the development of the eyes, or buds.

Seed sticks are usually cut about ten inches long (carrying usually three or more eyes) and these pieces are spaced several inches apart in the furrow at planting. Between the extremes of thick and thin planting we find all intermediate

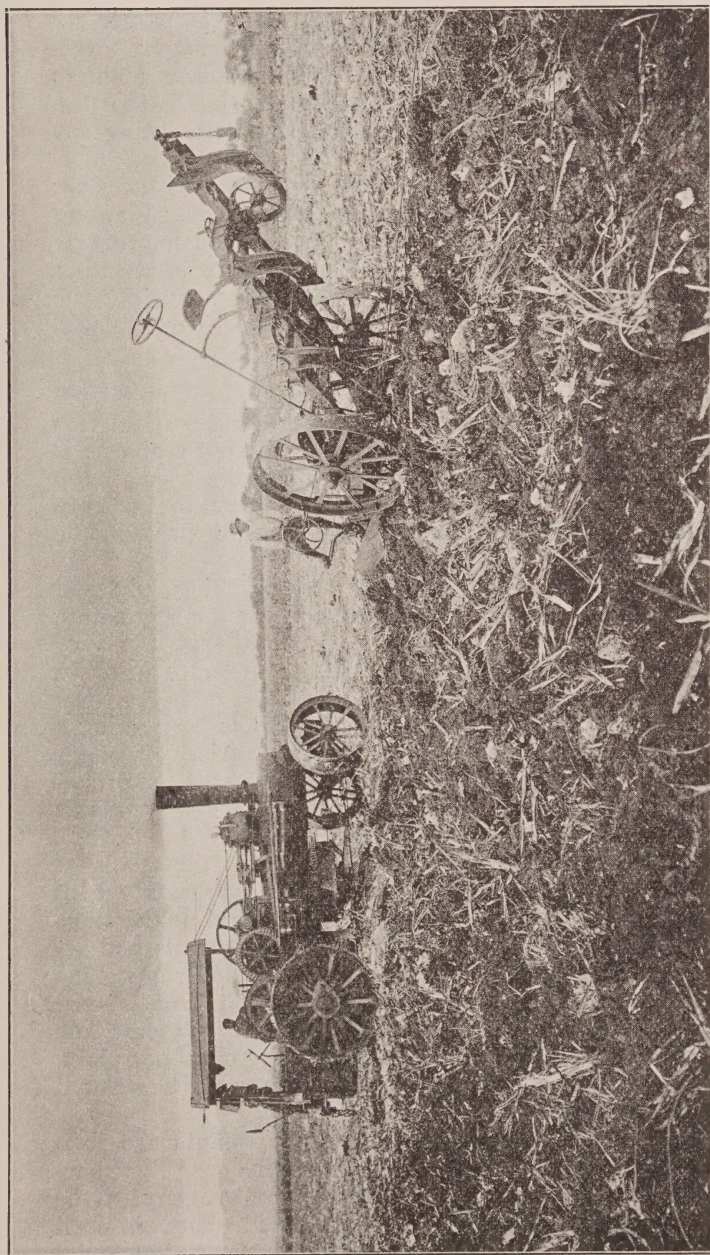


FIG. 10.—FOWLER STEAM PLOWING OUTFIT. Two Fowler steam engines are required. The engine shown here has just drawn the large plow to itself from the other end of the field and now the one at the other side of the field has begun to draw it back. The plow is reversible, with several plowshares on each side and two wheels in the middle. To reverse the plow, one end is tilted up in the air and the other dropped down into the soil, as shown in the picture above. These plows often go 20 to 24 inches into the soil, indicating that the steam engines have enormous pulling power. (Photo by R. W. Perkins, Honolulu.)

stages, as overlapping half, etc. When sugar is worth six cents per pound each seed stick may contain sugar worth about half a cent, and this cost sometimes influences planters to save money by planting thin, but if the planting is too thin (too far apart) the crop may be reduced by there being too few plants.

The thickness of planting depends on the season of the year, character of the soil and quality of the seed sticks. Planting during the winter months, or planting in poor or improperly prepared soil, or using the whole stalk of cane for seed rather than the tops only, all require thicker planting, even to the extent of a double continuous row of seed sticks being placed along the bottom of the furrow.

Selecting Seed—Many a farmer uses his poorest and most scrubby potatoes for planting in order to be able to sell his good ones, thinking that he is profiting thereby, but really he is losing heavily because the scrubby seed will make a poor crop next year and he will have very little to harvest or his crop will be of poor quality and will not bring the top price in the market.

Some sugar planters have done that same thing, planting their worst cane which was not good enough for the sugar mill, but most everybody in Hawaii now is convinced that it is very important to select seed from good fields in order to insure a good crop for the next year.

The Experiment Station of the H. S. P. A. has been doing a great deal of experimenting to improve the variety of sugar cane by careful selection of the best plants and stalks for propagation. This is known as **bud selection**. Some very valuable results have come from these experiments.

Bud selection means a careful examination of the stools of sugar cane and selection of seed cuttings from only those which are considered to be as near ideal as can be found at the time. One of the important characteristics looked for in this bud selection is the number of stalks to a plant. A good sugar cane plant must have at least five uniformly good stalks, and in some cases the minimum number may be placed even higher. The average field of today does not have five good stalks per plant, and it is believed that much larger yields of sugar can be secured by increasing the average.

The seed pieces so selected from desirable plants are then planted and watched to see if they perpetuate the desirable characteristics for which they were selected. The progeny of the good individuals is then increased by continued plantings until enough such desired seed cane is available to plant commercial sized fields.

Young Cane—In a short time after planting the seed sticks, the first shoots of cane begin to show above the ground and growth proceeds rapidly. At first there is only one stalk and then a little later another one appears beside the first and after a while a third, and others, grow up, finally making what is called a "stool" of cane. The successive growing out of these stalks is called "stooling out," or "tillering." A good stool at maturity will have from 5 to 10 stalks which have all grown from one or two eyes on the seed stick.

The underground stalk is continually growing and forming new joints and eyes beneath the surface of the ground and it is, of course, from these eyes that the new stalks of a stool grow.

Weeds—Along with the young cane come the weeds and if allowed to grow undisturbed they will choke out the cane. While the cane is young, weeds may be checked or killed out by cultivation, but later the size of the cane plants makes it difficult to take cultivators through the rows and then weeding with hand hoes must be resorted to. On one large plantation weeds have been controlled by the use of paper strips laid on the ground over the seed cane. This is known as **paper mulching** and is used extensively in pineapple culture but in sugar cane fields it is not used now as a method.

Another method of controlling weeds is by the use of a poison spray made of sodium arsenite. In one experiment a few years ago it was shown that a large saving can be made in the cost of cultivation by using this spray instead of hoeing out the weeds by hand labor. This poison spray is made as follows: Place 80 pounds of white arsenic and 20 pounds of caustic soda in fifty gallons of water and boil for seven hours. This is the stock solution and must be diluted with water before it is used as a spray. It is very poisonous and must be used with extreme caution. In spraying, one pint of this stock solution is mixed with five gallons of water. Knapsack pumps may be used for spraying and great care must be exercised not to get the spray into the growing part of the cane where the new leaves come out, for this will injure the plant. On the lower leaves the spray does some harm by "burning," but these leaves soon dry up and fall off anyway. Spray the weeds between the cane rows, for this "burns" the weeds and usually destroys them. Several applications a few weeks apart, however, are usually necessary for controlling the weeds thoroughly, because the roots may escape injury and will send up new tops.

Cutting Back

Sugar cane in Hawaii normally produces tassels during late November and early in December when the plants are fifteen to

eighteen months old. Any condition that is unfavorable to the best growth may cause premature tasseling. These unfavorable conditions may be too much or too little moisture, too low a temperature, disease, or perhaps lack of sufficient fertility in the soil. The plant seems to realize that under these adverse conditions it may not be able to exist much longer, so tassels are often produced far in advance of the normal maturing period of the plant. Generally such plants are inferior for seed.

The rate of growth of cane plants greatly decreases as the cool weather comes on in November and a certain amount of tasseling results. Stalks that produce a tassel begin deteriorating after several months; that is, some of the sugar in the stalk is changed to another kind of substance, resulting in a loss. The best juices, however, are often obtained several months after tasseling. Sometimes plants that have been growing only since April or May will tassel in November of the same year, and they cannot be harvested then, for they have not made half of the normal growth. To avoid this tasseling, the practice on some plantations has been to cut back in June or July, for if cut back at this time the plants will not tassel in November but will pass over to the following November when they are pretty nearly full grown and would be harvested shortly after anyhow. This, however, is being done less now than formerly. Forcing the young cane to grow fast in August and September has a tendency to stop tasseling, so many plantations practice that rather than cutting back.

While tasseling can thus be prevented by cutting back, it is done at the expense of several months' growth, and obviously sugar yields should be based on tons per acre per month, rather than merely on tons per acre taking no account of the time required to produce that yield.

Some experiments made by the Experiment Station of the Hawaiian Sugar Planters' Association show that the amount of tasseling is generally not as great as a casual survey of the field would indicate and that the loss of sugar resulting is not equal to the loss that results where two to four months' growth are entirely destroyed by cutting back. An experiment on the Oahu Sugar Company field at 550 feet elevation with D-1135 cane showed a loss of 1.16 tons sugar per acre due to cutting back. This field was previously harvested the first week in May and half of the field was cut back on July 7 when the cane was from twelve to eighteen inches high. The whole field was harvested August 9th to 13th the following year with these results:

Treatment—	Yields in tons per acre	
	Cane	Sugar
Cut back	89.61	12.28
Not cut back	97.06	13.44

Ratoons—Planting of seed cane is necessary only once in a period of five or more years, for after the stalks are cut off at harvest time there is a growth of new stalks from the eyes left under ground. This corresponds to the “volunteer” growth of certain other crop plants, but in sugar cane it is called “ratooning” and as this takes place several times, planters refer to first ratoons, second ratoons, etc. There are a few fields in Hawaii which have not been replanted for 20 or 30 years, but in most cases the virility or strength of the plant seems to run down and planting of new seed seems to be necessary.

Although sugar cane in Hawaii is a $1\frac{1}{2}$ -year or 2-year crop, some experiments show that it may be more profitable to harvest in a shorter time, say 15 or even 12 months. The yield of sugar per acre is less when harvesting is done early, but this loss might be made up in the more frequent harvests. For example, a field



FIG. 11.—Sugar Cane about ready for harvest (on the left) and young cane a few months old (on the right). (Photo by R. W. Perkins, Honolulu).

might yield in a 6-year period by the 2-year crop method perhaps 6 tons of sugar per acre per crop, or 18 tons per acre in the 6 years. By harvesting every 18 months the yield would be less, perhaps 5 tons per acre per crop, but there would be four crops in 6 years with a total yield of 20 tons per acre. The factor of increased labor costs in handling more crops must be considered in figuring which method pays the best returns.

WORDS TO REMEMBER

Contour—The outline of the land surface, its ups and downs and general slope; following contour lines means to so place plant rows that there is a continual downward slope in one direction, even though the rows are not in a straight line.

Germinate—Swelling and growing of the buds or eyes on a seed stick.

Mulch—A surface covering over the ground, as of straw, paper or even loose earth, to protect the soil beneath from drying out (or freezing, in a cold country).

Stock solution—A concentrated solution of spray material which must be diluted before using.

CHAPTER V

WATER FOR THE FACTORY

When a factory cannot obtain enough of the required raw products it cannot keep its machines working at top speed and there is some loss resulting in the output, explained Mr. Planter in continuing his part of the story of sugar. Nature's sugar factory is no exception to this. The two raw products required by this factory are air and water. We have already seen how air is drawn into the leaves from the vast supply in the atmosphere and it is hardly conceivable that there should be a shortage of this raw product. Of water, however, there may easily be a shortage for it is drawn from the soil and the amount in the soil changes greatly from time to time. Immediately after a hard rain the soil is wet, but a few days or a few weeks later it may be dry and its water supply very limited. Then the roots are unable to draw in all that they need and the little machines in the leaves are not given enough water and the manufacture of sugar is slowed down. So it is of very great importance that the water supply in the soil be maintained sufficiently to keep the sugar factory working at full speed.

In regions where it rains a good deal throughout the year the soil is usually well supplied with water, but if the rainfall is irregular with long periods when it does not rain, then the water supply is irregular and the sugar cane plant grows irregularly, rapidly for a time and then slowly. This is reflected in the long and short internodes of the stalk, as Mr. Botanist has explained. The only escape from this irregularity of water supply from rainfall is to irrigate the land with water obtained from rivers, springs, wells or reservoirs—that is, water that has fallen as rain at some other place and time. By means of irrigation we can regulate the water supply in the soil just as we want it and this makes more uniform and more efficient working of the sugar machines in the leaves which causes better and larger growth of the cane plants.

What Makes Rain?—Warm air is able to hold more water vapor than cold air; in other words, the moisture content of air varies with the temperature. For every 300 feet that you go up a mountain you will find the temperature lower by 1 degree Fahrenheit, and if you go high enough, you may get to a region of perpetual snow. When the air from the warm areas near the

ocean is forced up to the higher levels it is cooled and consequently must give up some of its water vapor, for we have already noted that cold air can hold less than warm air. The water vapor that is forced out of the air by this chilling process forms into myriads of tiny droplets which together constitute clouds. As these clouds are carried by the wind over high mountains the fine droplets increase greatly in numbers and joining together they form rain drops. In this way we get rainfall over the mountains and we may also get it at times on the lower land to leeward, when the rain clouds are blown down from the mountain tops.

Sometimes it is important to know how much rain falls in different places and this is measured with rain gauges. You can roughly measure the amount of rainfall by setting a can or tumbler out in the school yard and seeing how much is filled during a storm. This would not be accurate, however, because some would splash out. Standard rain gauges have the top constructed to prevent the splashing and also to reduce evaporation.

Of the water that falls as rain, a part evaporates promptly and is lost to the plants, another part sinks into the ground, while the rest collects on the surface and runs away to form streams and rivers.

Some of the rain water that is absorbed into the earth wets the soil and furnishes moisture to the plant roots there, but some of it may sink slowly through the soil into the rocks below, entering cracks and crevices. The water moves on downward under the action of gravity to a region which is called the **saturated zone** because all the pores in the rocks are filled or sat-

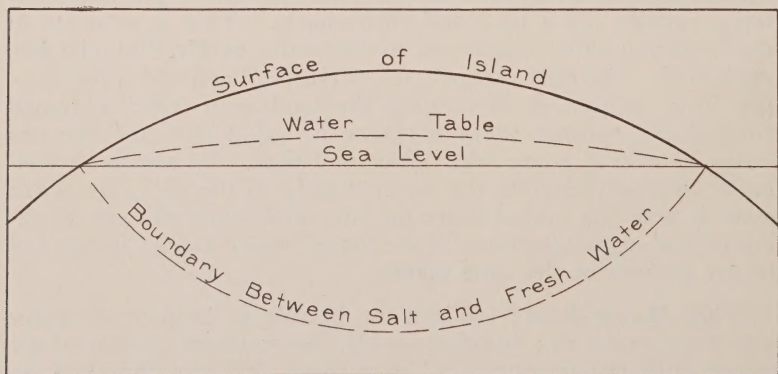


FIG. 12.—Water under an island percolates downward from the surface until it meets the sea water. This accumulation of fresh water is known as "ground water" and the upper level of it is called the "water table." (H. S. Palmer.)

urated with water. The upper surface of the saturated zone is called the **water table**, and is near to sea level in islands. If the rock has enough large pores so that the water moves readily horizontally seaward the water table will be very little above sea level, but in rocks through which the water moves with difficulty it will be backed up and the water table will be higher. This saturated zone contains fresh water which floats on salt water, because it is lighter than salt water. This condition is shown diagrammatically in figure 12, which is a vertical section across an imaginary island.

The water on its journey downward might come to an obstruction formed by a dike or sill. The sill or dike, or the combination of one or more dikes and sills, is very likely to cause a larger or smaller amount of water to be collected, forming what is known as a perched water table because it is above the main water table or saturated zone. The conditions in part of the Koolau Mountains of Oahu are of this sort and are shown diagrammatically in figure 13, where the heavy lines represent dikes and sills and the broken line represents the water table. Wherever a tunnel cuts through dikes water pours out of the cracks in the rock from the perched water bodies. In this way high level ground water may be gotten in favorable places in the mountains of Hawaii.

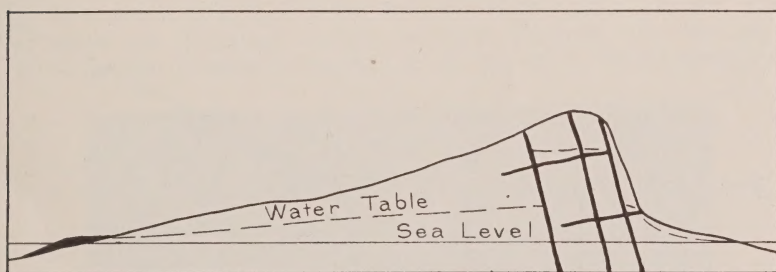


FIG. 13.—Ground Water collecting under this mountain moves to the lower levels (on the left) and forms an artesian basin at the extreme left. (H. S. Palmer.)

Water may also be gotten from the ground at low levels. In some places springs are made by the natural escape of water from underground. In other places wells may be sunk deep enough to reach into the saturated zone. Usually the water merely seeps into the well and must be lifted to the surface by a pump, but sometimes the water is under enough pressure so that it rises in the well of its own accord. These wells are called "artesian" because this type was first known in the province of

Artois in France. In some the water flows out at the surface of the ground making them "flowing artesian wells," but in others the pressure is not great enough to bring the water to the surface and they have to be pumped. These are called "pumping artesian wells." For a well to flow it is necessary that it be situated at a low elevation and that the water be under pressure.

In the Honolulu district, and elsewhere on Oahu, there is a great mass of mud, reef-rock, and so forth, lying along the shore. Its upper surface forms the plain on which much of Honolulu is built. The mud does not allow water to pass through it, and it resists the seaward movement of the underground water. The way in which the water is backed up and the water table is raised is shown at the left of figure 13. Wells drilled through the cap-rock of mud, etc., into the underlying, saturated lava-rock will have the water rise in them to a considerable height. Figure 14 is a more detailed cross section showing diagrammatically the conditions at Honolulu. The well at "B" will have water flow from it naturally as the mouth of the well is below extension of the level of the water table. The well at "C" will have to be pumped as its mouth is above the extension of the water table. Wells "B" and "C" will both yield fresh water but well "A" reaches down into the region of salt water below the fresh water, and will yield salt water.

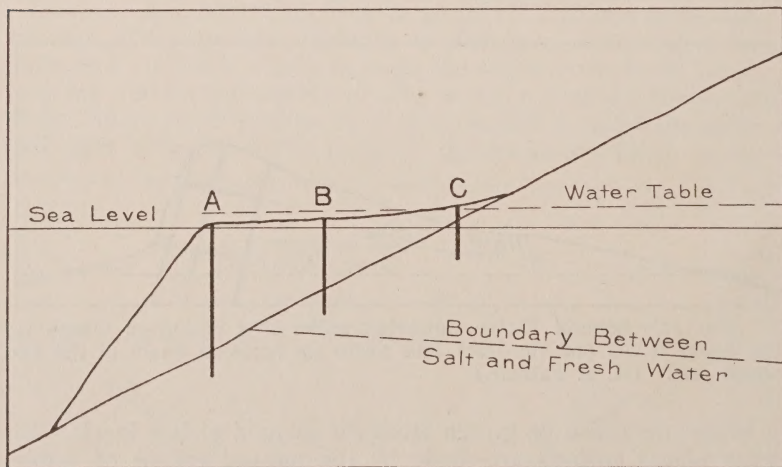


FIG. 14.—Three wells drilled in artesian basin. (H. S. Palmer).

Irrigation—If rainfall is too irregular or too small then irrigation must be resorted to, even though it is very expensive, for the increase in the yield of sugar will usually more than pay for the cost of irrigation. Ample water must be available

to the plant, for every pound of sugar requires over a barrel of water to be taken up and passed through its roots, stem and leaves and this must all come from the soil.

Good irrigation means the application of enough water to keep the soil moist, but without waste and excess, for too much water in the soil does no good and may do much harm. Some fields to be at their best require a great deal of irrigation water, while others may require much less. These differences are due to the kind of soil and subsoil, whether the latter is open and allows the water to go deep down beyond the roots of the plants, or whether it is hard and impervious and holds the water as in a basin.

The requirements of the cane plant at different ages are different and this must, also, be considered in planning the irrigation practice for each field. Just after planting, a good application of irrigation water is needed to make the eyes on the seed sticks swell and grow. This is equally important for the same purpose just after harvesting, for then the new ratoon growth must be encouraged and hastened from the eyes or buds on the underground stalks.

Only a few of our plantations in Hawaii have enough rainfall to supply the needs of the cane, and on the others water must be carried many miles through pipes and ditches to irrigate the fields. Many millions of dollars have been spent for pumps, tunnels, and ditches, and no other sugar country has as good an irrigation system as these Islands. As the cost of irrigation is more than that of all the other field operations

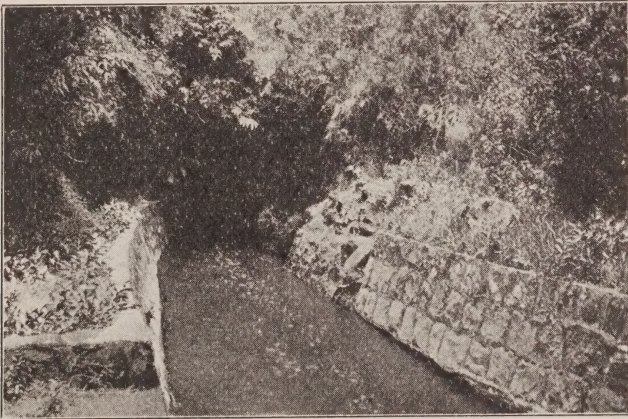


FIG. 15.—Irrigation water is brought through the mountains in tunnels like this and carried over the plains in ditches or canals. (H. R. Shaw.)

put together, you can see that water is an expensive and valuable article.

There are three chief sources from which this irrigation water is obtained: (1) surface streams and rivers, (2) tunnels into the mountains, and (3) wells.

Mountain streams, springs, and small rivers supply irrigation water for some plantations. This source may be cheap, as when a stream is merely diverted into the main irrigation ditch, or it may be very expensive, as on the island of Maui where over fifty miles of concrete lined tunnels and ditches carry surface water from the rainy mountain district to the dry cane lands.

Some of our plantations need water so badly that they have tunneled through the mountains that divide the dry leeward side of the island from the rainy windward side. This not only picks up surface water on the windward side but also collects underground water in the tunnel. An illustration of this type of water development is the Waiahole Tunnel on Oahu which extends for three miles into the Koolau mountains. In other cases, tunnels are driven into the side of the mountain to collect underground water which seeps through old lava tubes and cracks in the subterranean rock surface.

*** Furrow Irrigation**—In the irrigation system most commonly used in Hawaii (the furrow system) there are five main elements:

1. Main or supply ditch.
2. Straight ditches.
3. Level ditches.
4. Watercourses.
5. Furrows.

The straight ditch receives water from the main canal and delivers it to the level ditches which are placed from 200 to 300 feet apart, following the general contour of the ground. The watercourses are improvised channels running parallel to the natural water flow and delivering water from the level ditches to the furrows placed at right angles to the fall of the land. The furrows are generally from thirty to forty feet in length and are about five feet wide. Plant cane is located in the furrow so that the water runs in and around the cane stalk; ratoon cane is located on the ridges between the furrows.

Thirty to seventy furrows are fed from one watercourse.

* This chapter from here on was prepared by Mr. H. R. Shaw of the H. S. P. A. Experiment Station and a graduate of the University of Hawaii.

Each line (furrow) is filled with water, the line is then closed with a **pani** (dam) of cane trash and mud, and the water is applied to the next line.

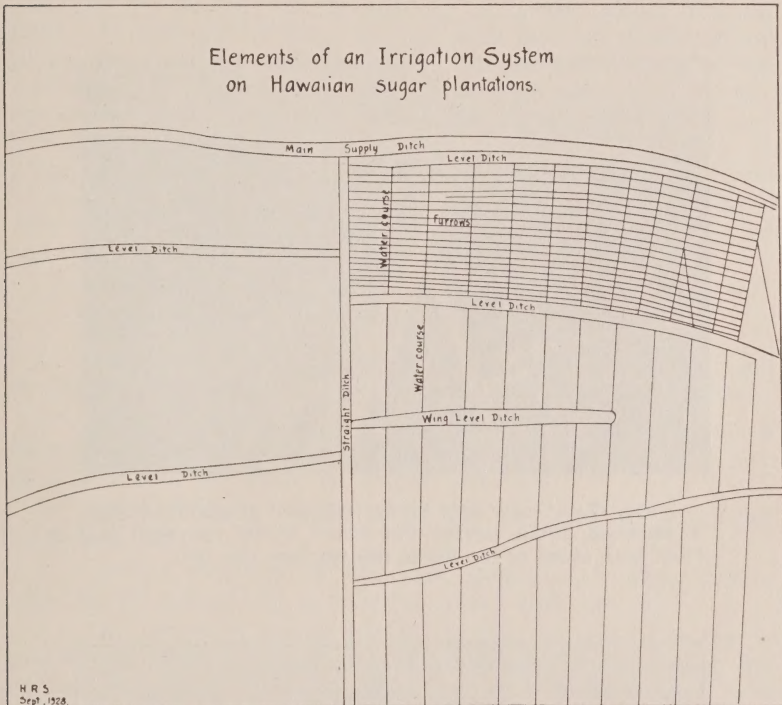


FIG. 16.—Diagram of an irrigation system on a sugar plantation. (H. R. Shaw.)

There are several modifications of this system. The bank between the ends of the lines may be cut so that the water proceeds to the end of the first furrow, overflows through an opening to the second, and thus zig-zags down the slope. This method wastes water, however, and is not a good practice. By cutting one line only (thus making a "U" of the first and second lines into which the water flows), the irrigator can work faster without using much more water than with the one-line system.

Some irrigators use a "two-way" system which is effective on level land. The watercourses are seventy feet apart instead of thirty-five feet, and water is diverted into the furrows on each side of the watercourse at the same time. Generally a small dam of earth is placed halfway between the watercourses so that the water flows thirty-five feet in each direction.

There are many other modifications of the furrow system, and men interested in irrigation are constantly trying to devise methods which will save water and increase the speed of the work.

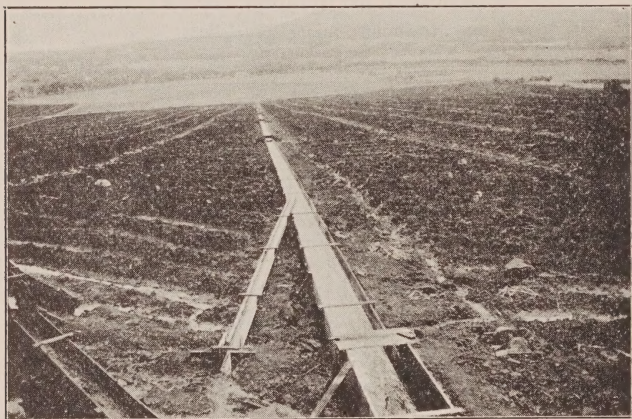


FIG. 17.—A new field being irrigated at planting time. A redwood flume carries the water across the field and from both sides of the flume the furrows are fed.



FIG. 18.—Putting a "pani," or dam, across the outlet of a furrow. This is made of cane leaves and trash and prevents the water from washing out a larger channel for itself.

Overhead Irrigation—Some of our plantations are experimenting with sprinklers, such as are used on lawns and gardens, for irrigating the cane. Lateral pipes laid in parallel lines on the surface of the ground carry the water into the field. At intervals of sixty feet on each line are placed stand-pipes, 10 feet high with sprinklers on the end. Some of the advantages of the system are: low labor cost, no furrows, no seepage, day and night irrigation, water regulation, and fire protection. The main disadvantages are: clogging of pipes, evaporation loss, and high cost of installation (from \$150.00 to \$250.00 per acre). With the exception of the Hawi Plantation on the island of Hawaii, this system of irrigation has not extended beyond the experimental stages.

Practical Points on Irrigating Sugar Cane

1. Apply water immediately after the cane is planted; and in the case of ratoons, as soon after harvesting as possible.
2. Light, frequent applications to young cane are more effective than heavy ones; with more mature cane heavier applications may be made at longer intervals.
3. Small streams of water should be used in irrigating steep **pali** land.
4. Careful preparation of lines, **panis**, and watercourses prior to irrigation will save water, time, and cane.
5. The irrigator should use as large a stream of water as possible without washing out his furrows or damaging his watercourses and ditches. The use of a large stream will result in an increased acreage covered per day, an actual saving of water, and a more even distribution to the field.
6. An average irrigator working under normal conditions should irrigate one acre in a ten hour day, using from 100,000 to 150,000 gallons of water.
7. In general, the growth of cane during the first summer is in almost direct proportion to the amount of water applied. During the winter months and second summer it is more economical to increase the interval between irrigations as the growth is not proportionate to the water applied.
8. When possible, weeding and stripping the cane, along water courses should be done prior to irrigation. Combining cultivation operations with irrigation often results in slow, inefficient work.
9. The cane should be irrigated just before or just after fertilization so that the fertilizer will become soluble and be available to the plant roots.

10. About five months before harvesting the interval between irrigations should be gradually lengthened; and three months before harvesting, irrigation should be stopped altogether in order to dry and ripen the cane and to develop the sucrose content.

Measuring the Water

If a merchant had no idea of the amount of money he was receiving daily nor of how he was spending it, we would call him a poor business man. For the same reason, a good irrigator must know how much water is being sent to his fields and whether or not he is using it to the best advantage. Because of the high cost of irrigation water, many plantations are making careful measurements of the water received and distributed. The measuring device generally used is a weir or a submerged orifice.

A weir may be defined as any notch of regular form through which water flows. In its simplest form, a weir is a gate or dam so placed across a stream that all the water must flow through an opening in the center of the gate's upper edge. The opening may be of any given size and should be lined with metal on the upstream side so that the water will fall sharply over it. The openings commonly used are rectangular or triangular in shape, the rectangular weir being considered more accurate. By knowing the size of the opening and the height of water passing over the crest it is possible to determine the amount of water flowing over the weir. An instrument which will

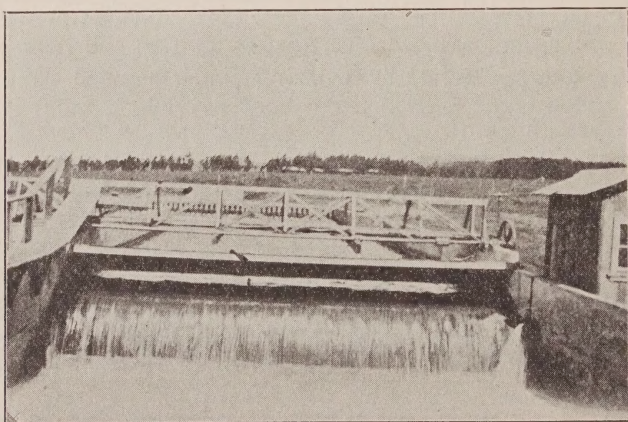


FIG. 19.—Weir used in measuring the flow of water in a ditch. (H. R. Shaw.)

graphically record this is usually used in conjunction with the weir.

A submerged orifice is nothing but a gate in the center of which is a hole (orifice) of given size which is constantly under water (submerged) during use. This gate backs the water upstream and as the water flows through the submerged opening, you can see that the water level on the upstream side of the gate would be higher than that of the downstream side. The difference between the two water levels is called the **pressure differential**, or the difference in head. With the size of the hole and the difference in head known, the discharge of water in the ditch may be computed.

The device most commonly used in Hawaii to measure water passing through a submerged orifice is the Great Western Meter. This meter consists of a brass cylinder at the base of which is a propellor. The shaft of the propellor leads to the top of the cylinder where a set of geared counter wheels records the water passing through the orifice much as a speedometer registers the number of miles an automobile travels. The difference in head causes the propellor and shaft to revolve, and the geared counter wheels record the total amount of water passing through the orifice.

The Reliance Meter is another of the submerged orifice type. This differs from the Great Western mainly in that the orifice is vertical instead of horizontal, and the meter operates by the flow of the entire quantity of water instead of by only a small part of the flow, as does the Great Western.

How to Make a Weir

The rectangular weir is not only the most accurate means of measuring water but is also the easiest to construct. The weir described here is suitable for measuring water in level ditches or in small straight ditches.

First, choose carefully the site for your weir. This should be in a section of the ditch where the grade is sufficient to prevent water on the downstream side of the weir from backing up and covering the crest. A **stilling pond** should be constructed on the upstream side of the point at which you intend to place the weir so that the water above the weir will be calm and quiet before it passes over the crest. The size of the pond varies with local conditions, but for the weir described here a pond 20 feet long, 6 feet wide, and 4 feet deep should be sufficient.

You are now ready for the carpentry work on your weir. With 1 x 12 inch boards, construct a wooden gate which will

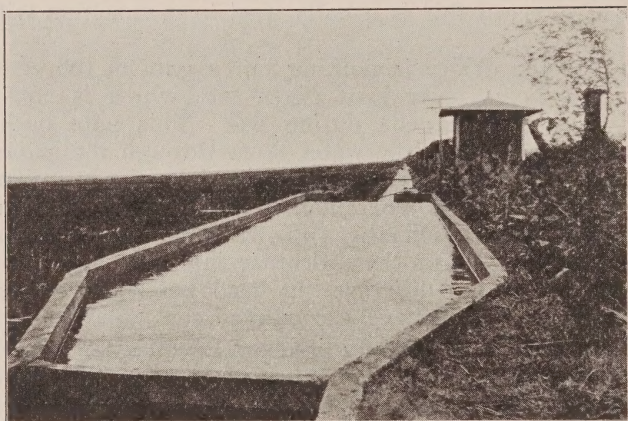


FIG. 20.—Weir Basin or Stilling Pond, to still the stream of water and make its measurement more accurate. (H. R. Shaw.)

be long enough to extend one foot into the bank on either side of the ditch, and wide enough to extend from the ground surface to one foot below the ditch bottom. For the size of stilling pond described above, the gate should be about eight feet long and five feet wide. Caulk the seams with tar so that no water can leak through the gate.

In the center of the upper edge of the gate cut an opening $24\frac{3}{8}$ inches long and $12\frac{3}{8}$ inches deep. Line the side of the opening which will face upstream with galvanized iron or other metal, so that the metal will extend $\frac{3}{8}$ inch in from the edge of the opening. Make sure that the metal (which is called the **crest** of the weir) is level from end to end, that the sides are vertical, and that the inside dimensions are exactly 24×12 inches.

Now place the weir gate in the ditch, taking care that the ends and base extend into the banks and bottom of the ditch as described above, so that the earth will not wash away from the sides of the weir and so that all the water will pass over the crest. Drive a 2×4 inch stake into the bottom of the stilling pond about six feet above the weir and one foot from the bank. Make sure that the top of the stake will be on an exact level with the metal lined bottom of the weir crest. When you are ready to measure the water flowing over the crest, place a ruler vertically on top of the stake and read the height of water on the ruler. This is more exact than to read the height of water on the weir crest itself. Measurements should

be taken every five minutes, and the average figured to determine the total flow.

You now have what is called a **standard two-foot rectangular contracted weir**; "standard" because it is the type adopted by the United States Government, "two-foot rectangular" because the crest is rectangular in shape and two square feet in area, and "contracted" because the sides are so far removed from the sides of the channel that the filaments of water are fully contracted as the water passes over the crest.

The following table will give you the amount of water flowing through the ditch if the height of water passing over the crest (or over the top of the stake) is known:

Irrigation Terms

The following are a few terms which are used daily by irrigation men, and with which everyone interested in irrigation should be familiar:

A **Round** is the number of days required to completely irrigate a field.

Interval is the number of days between one irrigation and the next.

A **Dry Spot** is an irregular irrigation of small patches of cane within a field.

Man's Water is the gallons of water used by an irrigator in one day. The amount varies on different plantations and with the soil, slope of ground, age of cane, and method of irrigation but is generally from 100,000 to 150,000 gallons.

A **Man Day**, on most plantations, is ten hours. This term is often used to denote the amount of labor required to irrigate a field. Thus if it takes 4.5 days for 5 men to irrigate a field, it is said that the field required 225.0 Man Hours ($4.5 \times 5 \times 10$) or 22.5 Man Day (225.0).

$\frac{225}{10}$

Acres per Man Day is the area irrigated in a ten hour day. If it takes 22.5 Man Days to irrigate a 25 acre field, the Acres per Man day will be $\frac{25}{22.5}$ or 1.11 acres.

$\frac{25}{22.5}$

A **Cubic Foot** of water is the volume of water contained in a vessel one foot square and one foot deep. It is a convenient unit for measuring volumes of water.

TABLE OF DISCHARGE

For Standard Two-Foot Rectangular Contracted Weir

Height of water over crest, in feet	Cubic Feet per second	Gallons per second	Gallons per hour	Height of water over crest, in feet	Cubic Feet per second	Gallons per second	Gallons per hour
.01	.007	.052	187.2	.51	2.302	17.219	61,988.4
.02	.019	.142	511.2	.52	2.367	17.705	63,738.0
.03	.034	.254	914.4	.53	2.434	18.206	65,541.6
.04	.053	.396	1,425.6	.54	2.500	18.700	67,320.0
.05	.074	.554	1,994.4	.55	2.567	19.201	69,123.6
.06	.097	.726	2,613.6	.56	2.635	19.710	70,956.0
.07	.123	.920	3,312.0	.57	2.703	20.218	72,784.8
.08	.149	1.115	4,014.0	.58	2.771	20.727	74,617.2
.09	.178	1.331	4,791.6	.59	2.840	21.243	76,474.8
.10	.208	1.556	5,601.6	.60	2.909	21.759	78,332.4
.11	.240	1.795	6,462.0	.61	2.979	22.283	80,218.8
.12	.273	2.042	7,351.2	.62	3.050	22.814	82,130.4
.13	.308	2.304	8,294.4	.63	3.121	23.345	84,042.2
.14	.344	2.573	9,262.8	.64	3.192	23.876	85,953.6
.15	.381	2.850	10,260.0	.65	3.263	24.407	87,865.2
.16	.419	3.134	11,282.4	.66	3.335	24.946	89,805.6
.17	.459	3.433	12,358.8	.67	3.408	25.492	91,771.2
.18	.499	3.733	13,438.8	.68	3.58	26.778	96,400.8
.19	.541	4.047	14,569.2	.69	3.66	27.377	98,557.2
.20	.584	4.368	15,724.8	.70	3.74	27.975	100,710.0
.21	.627	4.690	16,884.0	.71	3.82	28.574	102,866.4
.22	.672	5.027	18,097.2	.72	3.90	29.172	105,019.2
.23	.718	5.371	19,335.6	.73	3.98	29.770	107,172.0
.24	.764	5.715	20,574.0	.74	4.06	30.369	109,328.4
.25	.811	6.066	21,837.6	.75	4.14	30.967	111,481.2
.26	.860	6.433	23,158.8	.76	4.22	31.566	113,637.6
.27	.909	6.799	24,476.4	.77	4.30	32.164	115,790.4
.28	.959	7.173	25,822.8	.78	4.38	32.762	117,943.2
.29	1.010	7.555	27,198.0	.79	4.46	33.361	120,099.6
.30	1.061	7.936	28,569.6	.80	4.54	33.959	122,252.4
.31	1.114	8.333	29,998.8	.81	4.62	34.558	124,408.8
.32	1.167	8.729	31,424.4	.82	4.70	35.156	126,561.6
.33	1.221	9.133	32,878.8	.83	4.78	35.754	128,714.4
.34	1.275	9.537	34,333.2	.84	4.87	36.428	131,140.8
.35	1.331	9.956	35,841.6	.85	4.96	37.101	133,563.6
.36	1.387	10.375	37,350.0	.86	5.05	37.774	135,986.2
.37	1.443	10.794	38,858.4	.87	5.14	38.447	138,409.2
.38	1.501	11.227	40,417.2	.88	5.23	39.120	140,832.0
.39	1.559	11.661	41,979.6	.89	5.32	39.794	143,258.4
.40	1.617	12.095	43,542.0	.90	5.41	40.467	145,681.2
.41	1.677	12.544	45,158.4	.91	5.50	41.140	148,104.0
.42	1.737	12.993	46,774.8	.92	5.59	41.813	150,526.8
.43	1.797	13.442	48,391.2	.93	5.68	42.486	152,949.6
.44	1.858	13.898	50,032.8	.94	5.77	43.160	155,376.0
.45	1.920	14.362	51,703.2	.95	5.86	43.833	157,798.8
.46	1.982	14.825	53,370.0	.96	5.95	44.506	160,221.6
.47	2.045	15.297	55,069.2	.97	6.04	45.179	162,644.4
.48	2.108	15.768	56,764.8	.98	6.13	45.852	165,067.2
.49	2.172	16.247	58,489.2	.99	6.22	46.526	167,493.6
.50	2.237	16.733	60,238.8	1.00	6.31	47.199	169,916.4

1 Cubic Foot = 7.48 gallons
= 62.5 pounds (approximately).

Cubic Feet per Second (often called "**Second Feet**") is the number of cubic feet of water which will flow past a given point in one second.

1 Cubic Foot per Second = 7.48 gallons per second
= 26,929.87 gallons per hour
= 646,316.88 gallons per 24 hours

An **Acre Inch** is the volume of water which will cover an acre of land to a depth of one inch.

1 Acre = 43,560 square feet
1 Acre Inch = 27,154 gallons
= 3,630 cubic feet

An **Acre Foot** is the volume of water which will cover an acre of land to a depth of one foot. It is equal to 12 acre inches.

Acre Inches per Acre: the total acre inches of water applied to a field divided by the area of the field. If a 35 acre field requires 120 acre inches in one irrigation, the acre inches per acre equals 120

35 or 3.43.

Gallons per Man Day is equal to the total gallons applied to the field divided by the number of Man Days required. If 15 men use 1,832,650 gallons in one day, the Gallons per Man Day would be 1,832,650 or 122,177.

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Words to Remember

Artesian well—A well in which the water rises because of internal pressure.

Crest—The top surface of a weir over which the water flows.

Dike—An upright wall of hard, impervious rock extending through a part of the earth crust.

Evaporate—To pass off as vapor, as water changing to vapor.

Fahrenheit—A certain scale for measuring temperature, freezing point of water being 32 degrees and boiling point 212 degrees.

Leeward—The side of a mountain or island shielded from the prevailing wind, and therefore usually less rainy than the windward side.

Meter—A device or mechanism for measuring the flow of water.

Pali land—Steep hillside slopes (Hawaiian word).

Pani—Hawaiian word meaning a dam or obstruction placed to stop or divert the flow of water.

Pressure differential—The pressure created by water held at a higher level than the point at which it is flowing out; this pressure is measurable according to a certain formula of mathematics.

Rain-gauge—A device for measuring the amount of rainfall.

Saturated—Full of water, as a sponge.

Sill—A horizontal dike or wall in the earth crust (see dike).

Submerged orifice—A device for measuring the rate of flow of water through a hole in a gate, the gate impounding the water and the hole being below the surface of the impounded water (submerged). A meter at the orifice measures the rate of flow.

Subsoil—The soil beneath surface layer.

Water table—The upper limit of the portion of ground wholly saturated with water.

Weir—A device for measuring the flow of water through a notch in a dam placed across a stream; if the notch is square or rectangular it is a **rectangular weir**; if the notch is triangular, it is a **triangular weir**.

CHAPTER VI

FERTILITY AND FERTILIZERS

Although the sugar cane plant is a factory, yet in one very important respect it is not like the factories which men build, for nature's factory begins as a small thing as soon as the first leaf appears above ground and grows steadily larger every day, says Mr. Chemist, who has again taken up the story to tell about fertilizers. To support this steady growth and enlargement of the factory, the plant must obtain food for itself just as a boy must have food if he is to grow.

The plant's daily diet includes many things, chief of which is sugar. Of great importance, however, are several other things in this diet—nitrogen, potash, phosphates, iron and others. These are obtained by the plant from the earth, for in the soil are small quantities of all these which become dissolved in the soil water. The tiny roots which grow among the particles of soil absorb these liquids and pass them upward through the tubes of the roots and stem into the leaves. Now there is not usually a very large supply of these food materials in the soil and the roots are continually taking in as much as they can, which tends to reduce the supply. When the supply in the soil becomes exhausted or depleted, the plant cannot grow as it should, for it behaves very much like a boy who cannot get enough nourishing food—it becomes stunted and sickly. This, of course, is not satisfactory to Mr. Planter for he wants large plants which grow rapidly and make lots of sugar, so that he can have more sugar to sell.

It is necessary, therefore, that Mr. Planter should watch carefully the supply of these food materials in the soil and make sure that there is enough to enable the plant to grow as fast as it can. When the supply seems to be running low, he must put some more of the food materials into the soil. If he uses concentrated materials which he buys in bags we call it "commercial fertilizer" as distinct from barnyard manure, and this requires the expert help of somebody like Mr. Chemist who knows what kind of commercial fertilizer to use, for there are many kinds offered for sale. Most of them have three important plant foods—nitrogen, potash and phosphate—and what Mr. Chemist must do is find out how much of each of these three foods is needed in the different fields of sugar cane.

There are two ways of replacing these depleted materials in the soil—nature's way and man's way. Nature's way is to return the plant body itself to the soil after it has done its work and died. Leaves fall and finally the plant itself falls and decays and becomes mixed with the soil in the form of "humus" and practically all the foods it took out of the soil are returned and may be used over again. That is why forests have fertile soil even though they have been growing perhaps for centuries.

Man's way is to grow a crop, harvest it and take it away bodily, destroying what is not sold and consumed. Where there is little or no return to the soil, the soil foods are used up and have to be renewed by the application of fertilizers. This is why Mr. Planter has to fertilize his land, for he takes away almost the entire plant and must therefore replenish the food supplies in the soil. He sometimes burns the sugar cane field before harvesting, in order to get rid of the dry leaves and trash, but this method destroys the nitrogen in the dead leaves, which, if not burned, would help to replenish the plant foods in the soil.

The material left after the juice has been squeezed out of the cane stalk, called "bagasse," is commonly used as fuel to furnish the steam power necessary for the operation of the mill. The bagasse contains nitrogen, potash and phosphates. All the nitrogen and probably much of the phosphate and potash elements in it are destroyed in this process, but some of the last two elements will be found in the ash, and when this is applied as a fertilizer the waste is not complete.

The impurities in the juice are filtered out by means of filter presses and this filter press cake or **mud press cake**, as it is called, contains some nitrogen, phosphorus and potash, and also some lime as well. This lime was added to the cane juice to neutralize the acidity and cause the impurities to settle out. This material is used as a fertilizer.

The waste molasses contains a good deal of potash which is concentrated by burning the molasses. Molasses ash is used as fertilizer on some Hawaiian plantations. Molasses is sometimes used as a feed for plantation mules and other animals and can be used as a source of industrial alcohol. A great deal of molasses is shipped from Hawaii to California and used as stock feed.

Plantation Fertilizers

Commercial fertilizers are used in very large quantities on sugar plantations in Hawaii because these are more readily available and easier to apply than manure or similar materials. Commercial fertilizers are obtained from many parts of the world and are prepared for use in a great variety of forms and

combinations. The origin of these materials and the processes of manufacture necessary in furnishing commercial fertilizers to the plantation is a story of real interest.

A bag of commercial fertilizer comes near being romantic. Something is in that bag that came from the southern part of South America, something else from central Europe, something else from the South Sea Islands of the Pacific and perhaps several other parts of the world are represented there. But cosmopolitanism is not its only interesting characteristic. It is of very ancient lineage and brings to mind some very old history.

What comes from South America represents a picture of teeming bird life, living in ancient geological times through thousands of generations, with other interesting dramas of nature following their extinction and transforming their droppings into a valuable substance called Chile salt-peter.

What came from central Europe represents the picture of a world map very different from what we know now, when much of Europe was a sea and Germany a series of great inland salt lakes. Some of the stuff in our bag of fertilizer, Strassfurt potash, lay millions of years ago at the bottom of one of these salt lakes.

What came from the South Seas calls to mind a picture of swarming bats living by millions on coral islands, their droppings accumulating and changing chemically the coral rock beneath, to form phosphates.

There is also a story of southeastern United States when it was a part of the Atlantic Ocean, with myriads of ancient species of fishes, now extinct, living and dying there and their bones accumulating with other animal and plant debris at the sea bottom. When, later, this was lifted up by earth forces to form a part of our country, this ancient marine graveyard was lifted up also and gradually transformed into our great beds of phosphate rock.

But other pictures too, are brought to mind—of modern factories and man's inventive genius. Phosphates as a by-product of great steel plants went into that bag, and much that is there would be of comparatively little use to the farmer if it had not gone through elaborate and sometimes difficult chemical processes in huge manufacturing plants.

So our bag of fertilizer reminds us of long sea voyages, of ancient world scenes and modern factories.

Sources of Nitrogen

Chile Salt-peter—The most common source of commercial nitrogen is Chile salt-peter or sodium nitrate. This occurs in

Chile (South America) in immense quantities in deposits which accumulated in past ages from bird droppings. The crude material goes through a refining process before it is used as a fertilizer and usually contains about 15.5 per cent of actual nitrogen.

Air Nitrogen—Chemists have been working for years to find a cheap method of obtaining nitrogen from the air, for it contains about 79 per cent of nitrogen and 20 per cent of oxygen, both of which are necessary for the formation of nitric acid, and is therefore a cheap and abundant source of raw materials. All methods, however, for obtaining compounds of nitrogen with atmospheric nitrogen as a source require a large amount of energy or power and that makes it expensive—usually more expensive than Chile saltpeter.

Sulphate of Ammonia—A great rival of nitrate of soda at present is sulphate of ammonia, of which the principal source is coal. Coal contains about 1.5 to 2 per cent of nitrogen derived from the ancient vegetable matter which formed the coal. When coal is made into gas, part of the nitrogen is changed into ammonia and may then be made into ammonium sulphate containing about 20 per cent nitrogen. Not only gas works but blast furnaces, coke ovens, and shale oil works recover this very valuable product. When pure, the product is white, crystalline, and soluble in water; the commercial article varies in color, being usually grey or yellow due to traces of tarry matter. As a nitrogen fertilizer it is practically as effective as nitrate of soda and almost as rapid in its action.

Organic Nitrogen. In addition to these nitrogen compounds, various residues from slaughter houses, fish canneries and other sources are useful, as they contain organic nitrogen, and also phosphoric acid and potash in some cases. Among these may be mentioned:

1. Steamed bone. This consists of bones from slaughter and packing houses, which are treated with live steam before being ground into bone-meal.
2. Tankage, dried blood and waste material in slaughter houses and meat canneries.
3. Manure.
4. Filter-press cake.
5. Fish scraps, corresponding to slaughter house tankage.
6. Cotton seed meal, which is the residue of the extraction of cotton seed oil.

Sources of Potash

Potash is a very powerful alkali and is not applied in the pure form. By far the most important source of potash fertilizers is the famous salt beds at Strassfurt, Germany. These deposits, hundreds of feet in depth, are believed to have resulted from the drying up of an ancient sea.

Potash is also recovered as a by-product in the manufacture of cement. The fine dust which goes up the big smoke-stacks of cement plants is collected by an electrical contrivance and the potassium in it is recovered as muriate of potash. During the war, some cement plants received sufficient income from this source to pay the total expenses of the cement making process.

Kelp. There is some potash in kelp (seaweed) which is harvested by special gathering devices, dried, burned and the potash extracted from the ashes. This process cannot usually compete with other sources of potash, because it is expensive.

Potash was formerly obtained almost entirely by the extraction of ashes in iron pots, hence the name, "pot-ash." Wood ashes still constitute a good source for potash and are valuable because they contain many of the elements of plant food in addition to potash.

Sources of Phosphate

This is the third ingredient of a complete fertilizer and is given to the plant in the form of phosphoric acid. The four great sources of phosphoric acid are:

1. The phosphate rocks.
2. Basic slag (sometimes called Thomas slag).
3. Phosphatic guanos, which are the dung of sea fowls from which the ammonia has been washed out by the rain.
4. The bones of animals.

Bones. The use of bone as fertilizer dates back to 1774 and marks the beginning of the commercial fertilizer industry. The English first discovered its value when applied to worn out pastures and they imported large quantities from Continental Europe and later from America. The supply of bones left as deposits from past generations is very limited and we are at present almost wholly dependent on the livestock industry for our supply.

Bones were first applied to the land in large chunks, and ploughed under. The phosphorus becomes available very slowly in this way and is not properly distributed. Later, it was noted that the results were far better when the bones were ground up.

It was later found that the phosphorus was made more available by treating the ground bone with sulphuric acid before applying, producing what we now term acidulated bone meal. In recent years much of the bone has been steamed before using in order to remove as much of the fat and nitrogenous matter as possible, which has other values and no value whatever as a fertilizer.

Animal charcoal used in refining sugar is used again as a fertilizer after its usefulness as a filter is gone.

Mineral phosphates exist in almost unlimited quantities in North and South Carolina and Georgia, in the form of calcium phosphate rock. Phosphate rock has very little immediate value as a fertilizer because of its slow action, but becomes available to plants in time.

Treatment with sulphuric acid converts it into soluble superphosphate of lime, in which form it is very useful as a fertilizer. When the superphosphate is allowed to stand for some time, a portion of the soluble primary phosphate is converted into insoluble phosphate by contact with water. This is known as the process of "reversion" and that part of the phosphoric acid contained in the insoluble phosphate is known as reverted phosphoric acid.

Basic slag is a by-product of the processes of making steel. This contains from 12 to 23 per cent phosphoric acid and needs only grinding to fine powder to be available for use as a fertilizer. It neutralizes acid soils, on account of the large amount of lime present, instead of having a souring effect as do superphosphates. It makes more available the potash and organic nitrogen already in the soil.

Guano. Thousands of years ago, certain South Sea Islands were the breeding places for centuries of many sea birds. On these low lying islands the rainfall was very small and the excrement of the birds accumulated until it reached a depth of hundreds of feet. By chemical combination of this guano with the coral limestone of the islands, a rock which was rich in phosphate of lime was formed. This is mined today and shipped to all parts of the world as fertilizer material.

Other Fertilizer Constituents

In addition to these three common elements, occasionally some others are used as fertilizers.

1. Lime in the form of quicklime, lime stone or lime ashes.
2. Gypsum or hydrated sulphate of lime is of value.
3. Salt or sodium chloride has some value.

4. Magnesium sulphate, similar in its influence to salt and gypsum.
5. Iron compounds are supposed to have a stimulating effect on plants. As a local example, we may cite the spraying of pineapple plants with iron sulphate solutions as a cure for yellowing.

“High Grade” or “Complete” Fertilizer

Mixtures of fertilizers which include nitrogen, phosphorus and potash, although one of the latter two may be left out, are known commercially as high grade or complete fertilizers. Fertilizers are mixed before applying in order to save labor in application. One fertilizer, for example, may contain 11 per cent nitrogen and 6 per cent phosphoric acid, while another carries 8 per cent nitrogen, 7 per cent phosphoric acid, and 7 per cent potash.

Time of Fertilizer Application

Most of the high grade fertilizer is applied the first season and during the second season some additional nitrogen is applied. The less soluble fertilizers, like phosphates and potash, must be supplied early in the crop's growth, in order to give the cane plant more time to take them up.

Applying fertilizer shortly before harvesting is very poor practice because the plant does not have time to take it up, or if it does, it probably causes new growth which results in a larger cane tonnage but a much lower purity of juice.

Fertilizer for Sugar Cane

The amount of fertilizer to be applied must always be expressed in pounds of actual nitrogen, potash and phosphoric acid needed for each acre. This is necessary since the real plant food content of different fertilizers varies greatly. For example, two nitrogen fertilizers commonly used in Hawaii are saltpeter and sulphate of ammonia. The former contains about 16.0 per cent nitrogen or twenty pounds of actual nitrogen in each 125-pound bag. Sulphate of ammonia contains 20 per cent nitrogen or 25 pounds actual nitrogen per 125-pound bag. If the proper application for a certain field should be 100 pounds of actual nitrogen per acre, it is plain that it would require five bags of saltpeter but only four bags of sulphate of ammonia to supply the right amount. This same method of calculation must be used where applying potash and phosphoric acid fertilizers,

for these, too, vary greatly in their content of the essential plant foods.

The proper amount of fertilizer to apply depends entirely on the locality, and experiments must be placed on each plantation to determine this point.

A fertilizer should be applied up to the profitable limit. If the addition of fertilizer costing five dollars causes an increase in sugar yield worth ten dollars, the profitable limit has probably not been reached. But if nine dollars' worth of additional fertilizer adds only ten dollars more to the value of the sugar crop, the profitable limit has probably been exceeded, for the margin of one dollar over the cost of fertilizer is probably not enough to pay for the labor of applying it and for the increased cost of harvesting, milling and marketing the increased yield.

The problem is further complicated by the relative prices of fertilizers and sugar. When fertilizer prices are low and sugar prices are high, more fertilizer can be profitably applied. But when the reverse is true the profitable limit of fertilization would be much lower. Fertilizer is applied to a large extent early in the growth of the crop when the sugar planter can only guess at what the sugar price will be when the crop is mature. It can readily be seen, therefore, that the cane grower is up against a difficult problem.

The amount of water available must be considered, also, in connection with fertilizer applications. It would be folly to apply heavy doses of fertilizer when there is only a very limited amount of rainfall or irrigation water available to carry this fertilizer into the cane plant. Similarly, too heavy rains or irrigations can easily waste the fertilizer by washing it so deeply into the soil that the sugar cane roots cannot get it. Surface run-off water also carries away some fertilizer.

A survey of the many experiments carried out by the experiment station of the Hawaiian Sugar Planters' Association seems to indicate that the profitable limit of nitrogen application per crop per acre ranges between 75 to 300 pounds with the majority of the experiments indicating that 150 to 250 pounds is about the profitable limit. The profitable limit in the case of potash and phosphoric acid is much lower, ranging from nothing to about 100 pounds per acre per crop.

Some Practical Problems

Problem 1. A sugar planter wishes to apply 100 pounds of nitrogen per acre as a second season dressing, half to be salt-peter and half sulphate of ammonia. How many bags of each (containing 125 pounds) should he apply? (See data on preceding page.)

Problem 2. A high grade fertilizer contains 11 per cent nitrogen, 6 per cent phosphoric acid and 3 per cent potash. 1,000 pounds per acre of this fertilizer are applied the first season. Previous experiments on this field indicate that 250 pounds nitrogen, 60 pounds phosphoric acid, and 70 pounds of potash are the proper amounts to apply per acre. All the phosphoric acid and potash are to be applied the first season and 110 pounds of nitrogen should be applied the first season and the balance as saltpeter dressings the second season. Saltpeter contains about 16 per cent nitrogen, molasses ash contains about 30 per cent potash and superphosphate contains 21 per cent phosphoric acid. Which of these and how many pounds of each are necessary to supply the proper amounts in addition to the 1,000 pounds of high grade fertilizer applied the first season?

Green Manures

Sometimes a farmer grows a crop of grass or cowpeas or some other succulent type of plant and then plows the crop under before it is fully mature. The purpose of this is to incorporate into the soil some green vegetable matter to decompose and make humus which increases the fertility greatly. These crops are called cover crops or green manure crops, and are very beneficial to the regular crops that the farmer will plant later.

This practice is rather difficult to combine with sugar plantation practice, but sometimes a cane field is allowed to remain fallow for a year before replanting and it is very beneficial to grow a crop of some rank, succulent grass or other suitable plant and then plow the whole thing under.

Words to Remember

Fallow—A condition of resting, as when a field of sugar cane is not replanted but allowed to rest with perhaps a green manure crop grown on it.

Humus—Decaying or decomposing vegetable matter in the soil, a good agency for fertility.

Kelp—Gigantic sea-weed, sometimes harvested for commercial uses.

Manure—The droppings of barnyard animals, valuable for fertilizing the soil, both because of the nitrogen contained and the vegetable matter which makes humus; when a crop of grass, cowpeas or pigeon peas is grown and plowed under to furnish humus to the soil it is called **green manure**.

Nitrogen—A chemical element, gaseous in form and comprising about four-fifths of our atmosphere; when combined properly with certain other chemical elements it makes a very essential type of plant food (nitrates, nitrogenous compounds, etc.).

Phosphate—Combinations of the element phosphorus with other elements make another very essential type of plant food; these compounds are called phosphates.

Potash—Combinations of the element potassium with other elements make the third type of plant food very essential to the growth of all plants.

CHAPTER VII

VARIETIES OF SUGAR CANE

And now the story telling shifts back to Mr. Botanist, for the agriculture class has become so interested in the story of sugar that several trips have been made to the sugar cane fields and this wonderful factory built by nature has been closely studied. Going to different fields has led to the observation that the sugar cane plants are not all alike. The stalks are different in color and appearance, and the leaves are sometimes very rough and sometimes not. So Mr. Botanist has been invited to tell another chapter of this story, explaining about the different kinds of sugar cane plants.

Sugar cane is not all the same, he says, confirming what had already been observed. There are scores of different kinds which are distinct from each other in several more or less important characteristics. These different kinds we call **varieties** and to each we give a name, as we do to varieties of apples, bananas, hibiscus and many fruits and flowers. Some varieties of sugar cane produce more sugar than others do, some are more resistant to diseases and pests, some grow better at sea level and others grow better at higher elevations.

Every cane growing section is looking for a better variety of cane. A variety which does well in one section may be wholly unsuited to another. The rainfall, temperature, wind, insect pests, and fungus diseases all influence the growth of cane plants and these naturally vary greatly in different parts of the sugar cane world, and even on the same island the varieties which are grown on the higher lands are different from those on the lower elevations.

The ideal cane variety should have the following characteristics: upright growth, high sucrose content, resistance to diseases and insect pests, fair amount of fiber for bagasse, early maturity, easy milling and the tendency to many good ratoon crops.

Telling Them Apart

Varieties of sugar cane may be recognized by several distinguishing characteristics, some of them definite and some very indefinite. The most exact and definite way to distinguish one variety of cane from another is by the arrangement of the

hairs and veins on the little leaflike covers of the eyes, or buds, on the stalk. An expert in Java discovered not long ago that these differences are constant and distinct and therefore useful in determining exactly the varieties of cane. Pull off a leaf which covers an eye and examine the little leaflike bract that remains over the eye itself, and notice the little tufts of hair here and there. It is said that these are as definite in their arrangements as the whiskers of a cat. The Experiment Station of the Hawaiian Sugar Planters' Association is making a study of Hawaiian cane varieties on this basis.

Other ways of telling one variety from another are by the colors of the stalk, the average length and thickness of the internodes, the groove above the node, the characteristic appearance of the leaves (whether they lop down or stand out more stiffly) and the erectness of the stalks or their tendency to fall down toward the ground. These are all more or less indefinite and not exact, so that one has to be rather familiar with varieties to recognize each by these characters.

In earlier years it was the practice to search other sugar cane countries for desirable or promising varieties and import "seed" to Hawaii for trial. But in this way a number of very serious pests and diseases gained entrance to these Islands and consequently this importation of seed cane is now controlled by law, making it necessary to develop new varieties by breeding or cross-pollination and by watching the fields for what the scientist calls a mutation, which is a plant or stalk which happens to be very different from its fellows. The varieties discussed here are of both types—some imported and some locally developed.

Lahaina Cane

Lahaina cane, also known by other names in other cane countries, has been a most important variety in Hawaii. It was probably brought to Hawaii from Otaheite about 1854 and because of its rapid growth, high sucrose content, hard rind when mature and firm compact fiber, it became very popular and remained so until Lahaina disease became prevalent. Now this variety has been largely replaced by H-109, a seedling cane of Lahaina parentage. It is interesting to note that Lahaina cane has deteriorated in other countries also to a point where its production has been greatly curtailed or abandoned altogether in some cases.

Lahaina cane does not do well on high elevations because of its sensitiveness to cold, nor is it very resistant to drought. The leaves, especially the leaf sheaths, are covered with prickly hairs which are irritating to the skin. Some years ago more

than one-third of all the cane grown in these islands was the Lahaina variety, but now there is only a very small percentage of this variety.

Yellow Caledonia

About 26 per cent of all the cane that was harvested in the Territory of Hawaii in 1928 was of the Yellow Caledonia variety. Fifteen years ago it represented about 53 per cent of the total cane harvested, which indicates that this variety is decreasing, but very slowly. This cane is justly popular because of its upright growth, deep rooting habits, its tendency to shed the dry leaves (a valuable feature in wet sections), the good quality of the bagasse for fuel, resistance to wind and general hardiness against diseases and insects. It does not have as high sucrose content as Lahaina cane has.

H-109

About 43 per cent of the cane harvested in the Territory of Hawaii in 1928 was of the H-109 variety, while in 1918 only about 3 per cent of the cane was of this variety. It is rapidly increasing and its popularity on the different islands is shown in the figures giving the percentage of H-109 in the 1928 crops. They are about as follows: Kauai, 60 per cent; Oahu, 92 per cent; Maui, 84 per cent; Hawaii grows very little H-109 cane. An increasing number of new fields are being planted to H-109 every year, but it is said that only about one-half of the sugar land area is suited to this variety.

H-109 is a seedling cane of Lahaina parentage developed by the Experiment Station of the Hawaiian Sugar Planters' Association. Its strong points are heavy yield, high sucrose content and apparent immunity to Lahaina disease. The variety is rather long jointed and abundantly supplied with a greyish waxy coating. It has some drawbacks, however, which are quite serious. It does not stand drought very well, is readily attacked by the leafhopper and at higher elevations it is rather susceptible to eye spot disease. Many of the cane lands of Hawaii are high enough to have a relatively cool climate and H-109 will probably not become popular on these lands, for it is essentially a lowland cane for irrigated plantations. It does not possess the hardiness of Yellow Caledonia. It does well on those lands where Lahaina used to do well, and as old Lahaina fields are plowed up, they are very generally replanted to H-109 cane.

D-1135

D-1135, a Demerara seedling, has been grown on a commercial scale in Hawaii for about ten years and is slowly gaining in popularity. About 14 per cent of the 1928 crop is D-1135 cane. It ratoons well, sending up vigorous shoots through the cane trash, and is very resistant to eye spot disease and yellow stripe disease. It stands cool weather and heavy rains and is well adapted to the higher cane lands of Hawaii. The stalks are small, increasing the cost of harvesting and the juice is rather poor.

Other Varieties

Other varieties of lesser but increasing importance, including some seedlings which may replace H-109 in time, should be mentioned.

Badila—This is a rather soft, dark colored, short-jointed cane that is doing very well in some localities under lowland conditions.

Badila cane is rather brittle, easily attacked by rats and stem borers, and the juice tends to be dark colored but has a high purity. The cane tends to be rather straight and erect.

Rose Bamboo, and Striped Mexican are canes belonging to the Cheribon group and are grown to some extent in the Islands. Rose Bamboo is called Crystalina in Cuba, where it is a very important variety. Striped Mexican is quite popular on Maui, where it constituted about 10 per cent of the 1925 crop, but only about 5% in 1928.

Striped Tip has constituted about 5 per cent of the cane on the Island of Hawaii for at least 12 years. At 1,400 feet elevation in a windy exposed place it produced seven tons of sugar per acre. It is essentially an upland cane that stands cool weather well. It is a small, thickly stooling cane with dark red, pink and yellow stripes. It is a good ratooner. In rainy sections it "lalas" (shoots growing out of the eyes) badly because the dry leaf sheaths cling to the stalks, thus holding moisture and inducing eye growth. Yellow Tip has similar characteristics except in the color of the stalk, and is replacing Striped Tip on the Island of Hawaii, about 7 per cent of the total 1928 crop being Yellow Tip.

Seedling Varieties of Cane

Although sugar cane does not commonly form seeds in the tassels, sometimes a few seeds are developed and if a person will take the trouble to place some pollen on the flowers some seeds are quite apt to form as a result. Sugar cane seeds are

very small, inconspicuous things and have to be planted carefully and just so, or they will not grow. The little plants that grow from these seeds are called seedlings, to distinguish them from the young plants that grow from eyes or buds on a stalk (seed stick).

Seedlings have been grown in very large numbers, not for field planting but in the hope that one or two plants out of several thousand might show some desirable characteristics for propagation on a large scale for field planting. It was in this way that the H-109 variety was discovered and has become a very extensively planted variety.

Variation of Seedlings

It is important to remember that an eye or bud on a stalk is simply a tiny stalk and will grow into the same kind of a stalk, or stool as that on which it was formed. And in contrast, remember that seed which forms in the tassel represents two parents, for the flower and the pollen which unite to form the seed usually are of two distinct and individual plants. The double parentage unites two sets of characters, instead of only one as in the eye, and this makes the seedling plant take on some of the characteristics of both parents but it will not be exactly like either one of them. Just as the children in one big family are apt to be very different from each other, so the seedlings that grow from one tassel will be very different from each other. This tendency toward variation gives us a good chance to grow a lot of seedlings, all different, and find a few that have good characteristics and which may deserve to be tried out on a large scale. This is what is called the seedling work of the Experiment Station.

In this seedling work there are two ways of obtaining the seed. One way is to gather tassels and bed them in such a way that the few seeds that happen to be there will fall down and grow. In this way only one parent is known, the plant that formed the tassel. The other parent, from which the pollen came, is not known.

The other way is to place pollen dust of some particular cane plant in the flowers of another cane plant and at the same time protect the latter from other pollen that might be blown in by the wind. In this way seeds are formed and we know both parents. This is a more exact method and is being used more and more each year, particularly since a way of keeping tassels alive two or three weeks after cutting has been discovered.

The splendid record of H-109, which is a seedling cane, has resulted in great interest being shown in seedling work. Pre-

vious to 1888 it was generally assumed that sugar cane could not be grown from the seed in the tassel.

The first seedling work in Hawaii was done in the winter of 1904 and 1905 and in these only the female parent was known. A few years later a few fertile seeds were produced by hand pollination and thus both female and male parents were known. The greatest chance of success seemed to be the growing of many thousands of seedlings of which only the female parent was known, for this was easier and quicker, and this is the way the bulk of the work has been done.

The mature tassel is bedded upon a suitable soil mixture, the best possible moisture conditions are supplied, and as some of the seeds germinate the tiny seedlings are transplanted from one container to a larger one and grown there until they are large enough to plant in the field.

All seedling canes are carefully watched for desirable characteristics, those that are promising are continued and if good enough will eventually be given a number as was the case with H-109. The inferior ones are abandoned. Even some promising seedlings are abandoned after being carried along some years, because they may prove poor ratooners or show susceptibility to plant diseases or have a poor quality of juice or develop other undesirable characteristics.

Bud Selection

"Bud Selection" is the careful selection of seed to get the very best, instead of using just any old stuff for planting. It is based on the scientific principle that certain characteristics are carried along from one generation of cane to the next when pieces of the stalk (seed sticks) are used for planting. A certain stool of sugar cane, we will say, is an especially good one, having a good number of stalks and all the stalks rich in sugar. Beside this good stool we will say there is a poor one, with few stalks and rather poor in sugar. It is probable that the first is naturally a good plant and the second naturally an inferior one, and if you take seed sticks from the good plant and grow these you will be quite apt to have good plants as a result.

The goal in view in the bud selection work being carried on by many of the plantations in Hawaii is to increase the total yield of sugar from each acre of cane. This goal, it is hoped, will be reached by discovering the best stools of cane and then propagating from those stools until a whole plantation represents the descendants of those superior stools, for in that way it is expected that the sugar yield should be increased materially.

Some remarkable improvements have been secured by bud selection in the orange orchards of Southern California. It is claimed that the average yield of oranges per acre has been practically doubled during the past ten years by the elimination of inferior trees through bud selection.

Words to Remember

Cross-pollination—The union of pollen of the flowers of one plant with the seed-forming part of the flower of another plant.

Lala—Hawaiian word for the young shoots that grow out from the eyes or buds of a standing cane stalk.

Mutation—An abrupt change in the characteristics of an individual plant or animal as compared with its parents; slight changes occur in all offspring, but only rarely do the sudden, large mutations occur.

CHAPTER VIII

INSECT ENEMIES OF SUGAR CANE

Every one who has watched growing plants knows that they are sometimes injured by insects, and Mr. Planter says that he has to be watchful always to protect his sugar cane against these enemies. Several times in the past thirty years some new kind of insect enemy has suddenly appeared in the cane fields of Hawaii and Mr. Planter and his neighbors have had to wage war against the invader. This has sometimes been very costly warfare but it has to be done, nevertheless, for the very existence of the sugar industry may depend on it.

One day in 1901, so Mr. Planter's story continues, a new kind of an insect was noticed on sugar cane leaves on one of the Oahu plantations, but nobody seemed to be worried about it, for the insect was very tiny and did not seem to eat holes in the leaves. A few months later, however, people began to remark about the abundance of these insects, which by that time were popularly known as **leaf-hoppers** because of their habit of jumping or hopping when anyone would try to catch them. They could fly, also, and sometimes many thousands of them would fly around above the sugar cane plants, making a sort of "cloud" of leaf-hoppers, so abundant were they. Then the people became much worried, for it was found that these insects were sucking out the sap from the leaves and really doing very much serious damage. One tiny leaf-hopper could not suck out enough sap to hurt the plant but thousands together sucked out so much that the plant was starved for lack of food and could not grow properly.

The trouble increased greatly in the next two years, and the cane fields were so starved and sick that many of Mr. Planter's neighbors became discouraged and feared that they would have to surrender to this enemy. But meanwhile, Mr. Entomologist, who knows all about insects, had been hired to make a special study of the leaf-hopper and devise some way of waging war against this horde. He tried several methods of killing them, but found that they multiplied more rapidly than he could kill them, and so he turned his attention to the scheme of finding another kind of insect which would devour and destroy the leaf-hopper. This finally proved to be successful and the enemy was at last subdued after several years of hard work.

The story of this struggle, told by Mr. Entomologist, is almost as interesting as the story of a real war. The leaf-hopper which

became so suddenly an enemy in 1901 was a regular resident of Queensland, Australia. A few years previous to that time a shipment of sugar cane seed-sticks had been brought to Honolulu from Queensland and in these sticks there must have been some of the eggs of the leaf-hopper. These tiny eggs, so small that you could scarcely see them, were the beginning of the terrible leaf-hopper scourge that nearly wrecked the whole sugar industry in Hawaii.

Once established in Hawaii, they multiplied very rapidly, for there were very few natural enemies here to kill them and climatic conditions were apparently very favorable. Each female lays 60 to 200 eggs and there are about six generations each year. Mathematical computation from these figures will get us some very large totals in the course of a few years, so that we can readily understand how such a fearfully numerous invading army could have developed in a few years from a few chance immigrant individuals. One female at the start would in a year's time have over one million offspring!

When the usual methods of fighting insects failed (sprays,

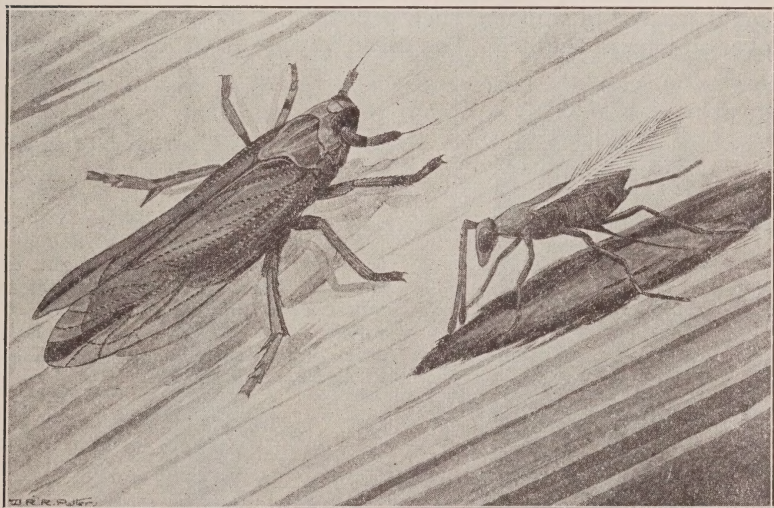


FIG. 21.—LEAF HOPPER (left) and EGG PARASITE. The sugar cane leaf-hopper shown here is very much enlarged and the parasite wasp is in the same proportion. Notice the feelers in front of the little wasp, bent down to discover where leaf-hopper eggs have been buried in the cane leaf. At her rear end the wasp has a little egg-tube which is like a dagger and by means of this she pierces into the cavity where the leaf-hopper eggs have been placed and inserts one of her eggs which causes the destruction of the other. She is shown standing over an egg cavity ready to deposit her eggs. (H. S. P. A.)

poisons, traps, etc.), it was evident that some other way must be found to kill them. So Mr. Entomologist went to Australia and Fiji and other places where sugar cane grows and where the same kind of leaf-hopper lives, searching all the time for different kinds of insects which eat or destroy the leaf-hoppers, for he knew that there is a continual warfare among insects, one kind preying upon another to satisfy hunger. He found several kinds of insects which catch and devour leaf-hoppers, and some of these he succeeded in shipping alive to Honolulu where they were turned out in the cane fields.

His best discovery, however, was of some tiny wasps scarcely a sixteenth of an inch long. These little wasps, he learned, lay their eggs inside the leaf-hopper eggs and the tiny worm which hatches out eats up the leaf-hopper egg and so prevents it from hatching. These wasps have a very short life, each generation living only about 10 to 15 days, while a generation of the leaf-hopper lives two to three months. This results in a much faster rate of multiplication of the parasite wasps than of the leaf-hoppers. It seemed to Mr. Entomologist as though these little wasps could conquer and wipe out the enemy in Hawaii if he could succeed in shipping such delicate and short-lived creatures over so long a distance. The ocean voyage from Australia took

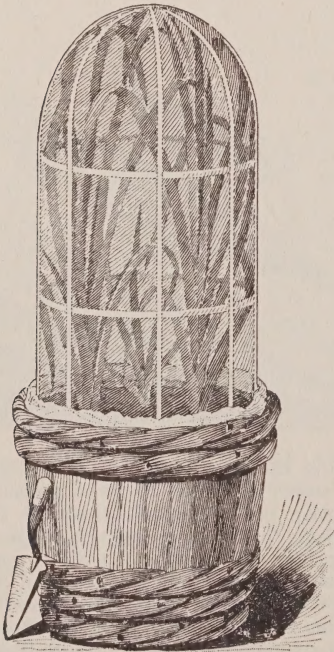


FIG. 22.—In this way delicate parasite friends were brought to Hawaii from distant countries. Sugar cane plants were grown in wooden tubs and covered by cloth nets. (Illustration loaned by H. S. P. A. Exp. Sta.)

longer then than it does now and was much longer than the span of life of the wasps. However, he devised a scheme of growing a sugar cane plant in a tub inside a cage enclosed by cheese-cloth and placing a large quantity of leaf-hoppers and parasite wasps in the cage and then placing the whole thing on a Hawaii-bound steamer, and in this way he succeeded in landing live wasps in Honolulu. The particular wasps which started off on this long voyage died en route and probably it was the grandchildren which arrived in Honolulu. They seemed to like the new home and multiplied rapidly.

Within a year or two after the arrival of these little wasps it was plain that the leaf-hopper was getting the worst of the fight and things looked more hopeful for Mr. Planter and his neighbors, and the little wasps* continued the warfare steadily, reducing the numbers of the leaf-hopper so greatly that the pest was no longer feared by all. In some places, however, the enemy still remained in abundance and caused much trouble, so Mr. Entomologist made another trip to Australia a few years ago and this time found another kind of insect to attack the leaf-hopper. It was a tiny bug with a sharp beak and a special fondness for fresh leaf-hopper eggs. The leaf-hopper deposits her eggs in a little hole which she makes in a cane leaf, and this new bug† runs over the leaf surface and searches out these buried eggs of the leaf-hopper, piercing them with the sharp beak and sucking out the contents.

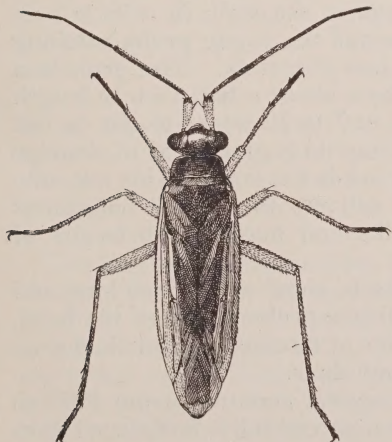


FIG. 23.—This is the tiny bug, (*Cyrtorhinus mundulus*, which finally brought the leaf-hopper under complete control. The actual size of the insect is shown by the short line on the right. (H. S. P. A. Exp. Sta.)

* These parasite wasps are of several species, the most abundant being *Paranagrus optabilis*, *Paranagrus perforator*, *Anagrus frequens*, *Ootetrastichus beatus* and *Ootetrastichus formosanus*. These are all very tiny wasps, not easily seen by the casual observer. Some of them are pictured on another page.

† The scientific name of this is *Cyrtorhinus mundulus*. It was discovered in Queensland by Dr. Frederick Muir and brought to Hawaii on June 21, 1920.

This new bug, when brought to Hawaii, proved to be the most effective of all the leaf-hopper enemies which have been imported and he has made the leaf-hopper so scarce that you very seldom see any at all. So the leaf-hopper scourge is now only a nightmare, at the memory of which Mr. Planter still sometimes shudders.

But the war against insect enemies did not end when the leaf-hopper was finally vanquished, for there are other kinds which injure the cane plants, so Mr. Entomologist's story runs on. There are grasshoppers and caterpillars which eat the leaves and there are mealy bugs and plant lice which suck out the sap; there is a beetle which lives inside the stalk, boring long tunnels through the spongy tissue where the sugar is stored; and there are other insects that live under ground and eat the roots of the cane plant or suck out the sap inside the roots. No part of the plant escapes, but fortunately, the injury is not very great for there are many parasites which prey upon them and reduce their numbers below the point of great danger. Two of these deserve a little more attention in this story, the beetle borer and the anomala beetle.

The beetle borer * is a weevil or snout beetle about a half inch in length which has the habit of boring channels inside of sugar cane stalks. The grub or larva of the beetle is the fellow that does the boring and he is after food when he does it, the juice of the pithy part of the stalk being very much to his liking.

The female beetle lays her eggs in the stalk in a little hole which she gnaws for the purpose and the young grubs hatching from these eggs eat their way into the stalk. The grub is a dirty white, plump footless creature, about a half inch in length when full grown. It requires from 7 to 12 weeks to get its full growth and during that time it may do a great deal of damage by eating out extensive channels inside the stalk. This not only reduces the tonnage of cane for delivery to the mill but causes fermentation in the injured stalks and may be the means of introducing disease germs.

The adult beetle is brown or black, about a half inch long and easily recognized by the long, bill-like prolongation of the head. The beetle lives a good many weeks or months, the female depositing a few eggs per day for many days.

Parasites were hunted for in several countries from 1906 to 1909, but only one parasite was successfully introduced into Hawaii. This is a fly which looks a good deal like a house fly, and has been very effective in reducing the borer in numbers.

This parasite fly † lays its eggs at the entrance to the beetle

* Known by the scientific name, *Rhabdocnemis obscura*.

† *Ceromasia sphenophori*.

grub's channel. The maggots hatching from these eggs are footless, but they manage to wriggle into the channel and follow it until the beetle grub is reached. The parasite attaches itself to the grub and for several days or weeks sucks out its vitality, finally killing the grub before it can turn into a beetle.

The parasite fly was introduced from New Guinea* in 1910 and by 1916 seemed to have reached its maximum development, and since then it has persisted as a very effective check upon the beetle pest.

Other natural enemies of the beetle borer are birds, toads, rats, mongoose and a parasitic fungus. These and other natural agencies serve to reduce the ranks of the enemy.

It should be especially noted that the burning of cane trash before harvesting is a very effective means of reducing this pest, as great numbers are destroyed by the heat and flames. Baiting and trapping, hand collecting of beetles and other artificial means of control have been resorted to with beneficial results.

A beetle (called **Anomala**), closely related to and resembling the well-known Japanese rose beetle, a few years ago gained entrance into Hawaii in some way and threatened to become a very serious sugar cane pest. The grub of this beetle lives underground and prefers to eat the small roots of the cane plant instead of the decaying organic matter in the soil which is the food preferred by its cousin, the rose beetle.

The loss of its feeding roots causes the cane plant to sicken and finally die. The infested areas expand in radius very gradually, indicating that the insect is not able to freely and widely disseminate itself. Before it could spread over the entire island and become a pest of very great importance, it was brought under satisfactory control by an introduced parasite. Various schemes for killing this beetle under ground were tried for several years, chiefly the fumigation of the soil with carbon disulfide, but this proved to be a very expensive method and not as effective as desired.

The lack of success in these efforts, and the results previously obtained by parasite introduction caused Mr. Planter to turn his attention to the search for natural enemies, for apparently this new pest (first observed in 1912) was an immigrant and had succeeded in arriving here unaccompanied by parasites. So Mr. Entomologist went on another long search in several countries around the Pacific and finally he discovered a parasitic wasp in the Philippine Islands which on being brought to Hawaii set to work immediately attacking the **Anomala** pest.

The wasp (**Scolia**) is a little smaller than a honey bee and

* The story of the search for this parasite is interestingly told in Bulletin No. 13 of the H. S. P. A. Experiment Station.

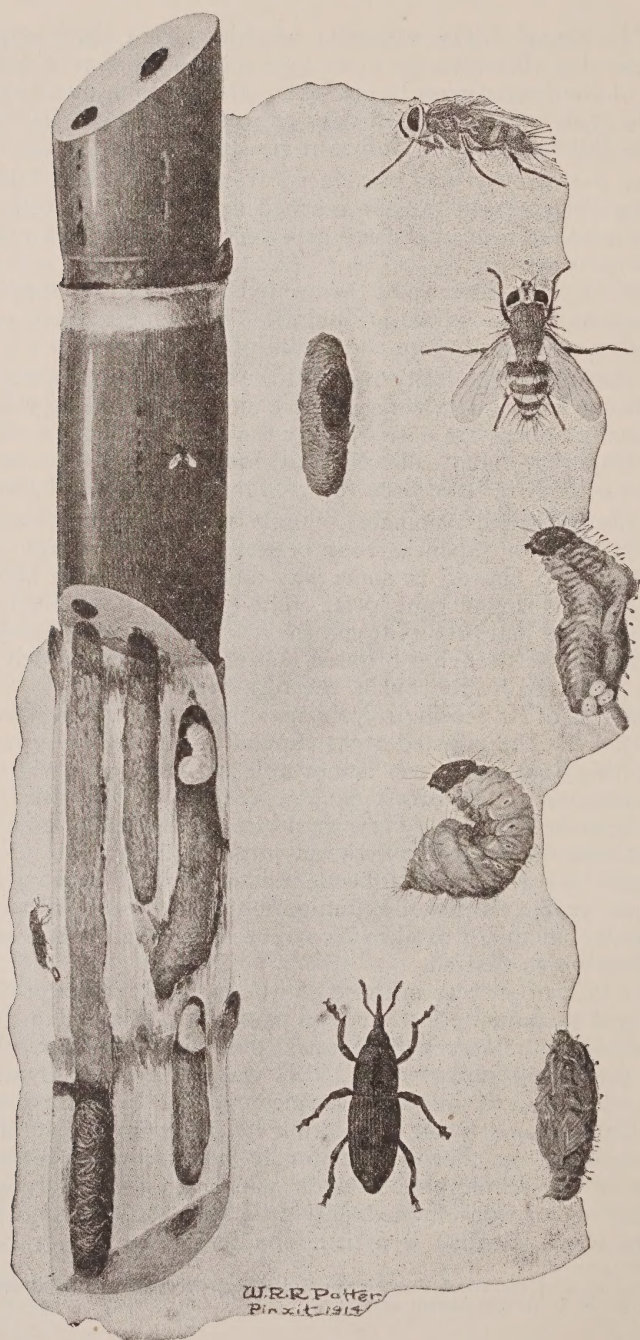


FIG. 24.—SUGAR CANE BORER, a large weevil (beetle) which bores through the cane stalk and does serious damage by reducing the yield of sugar. The egg is deposited in the stalk (see left hand margin in picture); the grub lives in the stalk, the adult beetle emerging at maturity.

This pest is partly controlled by a parasite fly which somewhat resembles the housefly and is shown in the illustration at the top (right). (Illustration loaned by H. S. P. A. Exp. Sta.)

more slender and delicate in appearance. The female digs down into the soil in search of the beetle grubs, which she stings and on the body deposits one of her eggs. This egg hatches, the young parasite grub or worm feeds at its expense, eats into the body of the beetle grub and finally causes its death before it turns into a beetle.

The *Scolia* parasite seems to prefer the *Anomala* grub as food for her young, but if none are to be had she will take the Japanese rose beetle grub as second choice. This has resulted in the almost complete extermination of the *Anomala* beetle, contrary to the usual procedure of parasitism, for the parasite has been able to maintain its abundance by living on the rose beetle and yet preferring the other and attacking it whenever any could be found.



FIG. 25.—SCOLIA WASP, (enlarged several times natural size). The female wasp, flying over the ground, is able to tell where there is a grub several inches under the ground and digs her way down until she finds it. She stings the grub to paralyze it and then lays an egg on it.

To guard against any more insect pests coming into Hawaii, the government has passed **quarantine** laws which prohibit the importing of sugar cane and many other plants from foreign countries, because of the danger that there might be insects or eggs in them. Then, too, everything which comes in is examined to see if there are any dangerous insect pests which might become established in these islands. The things which cannot be imported are:

Sugar Cane—from any part of the world, except by special permit.

Banana plants, fruit or shoots from any part of the world.

Pineapple plants from any part of the world, except by special permit.



FIG. 26.—The Anomala Beetle threatened for time to destroy the sugar cane industry of Oahu, but it was conquered by a parasite wasp. The illustration above shows a cane plant with its roots mostly devoured by this beetle. On the right are shown the grub (above) which does the damage, and the pupa (middle) in which the grub is changing into the winged adult, and the beetle (below) which is the adult stage of the insect. The female beetle lays her eggs in the ground at the base of a sugar cane plant so that the young grubs may easily find food (the cane roots). (H. S. P. A. Exp. Station.)



FIG. 27.—ANOMALA BEETLE GRUB, with *Scolia* egg attached (greatly enlarged). The grub is on its back, with the egg of the parasite fastened at about the middle of the ventral side. This egg hatches in a few days and the young parasite begins eating the grub. (H. S. P. A.)

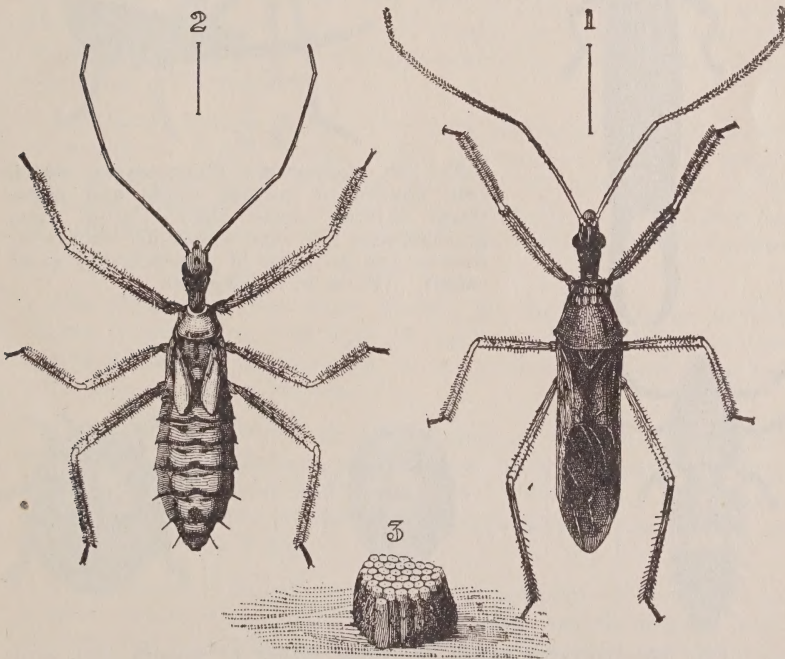


FIG. 28.—ASSASSIN BUG, which devours leaf-hoppers, mealybugs and other soft-bodied insects on sugar cane, corn and other plants. It is a beneficial insect. (H. S. P. A. Exp. Sta.)

Coffee plants from any part of the world.

Live Animals—flying fox (fruit eating bat), land crabs, birds, reptiles or insects liable to become injurious. This does not prevent the importation of beneficial birds, insects, etc., provided special permission is granted by the Board.

Soil from any part of the world.



FIG. 29.—EARWIG, a common insect (much enlarged) which eats other small insects. (H. S. P. A. Exp. Sta.)

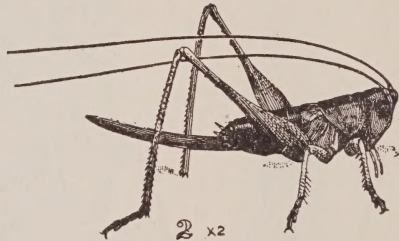


FIG. 30.—LONG-HORN GRASSHOPPER which eats flowers of various kinds and sometimes injures sugar cane. Unlike most grasshoppers this kind sometimes eats other insects and so may be beneficial to some extent. (H. S. P. A. Exp. Sta.)

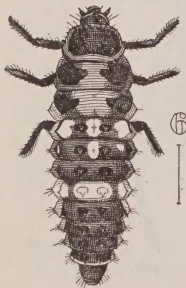


FIG. 31.—LADYBIRD BEETLE in three stages of growth, (5) adult beetle, (6) grub, and (7) pupa. All are much enlarged, the actual size being shown by the line under the numerals. These are sometimes called lady beetles or ladybugs. They are beneficial, as they eat large numbers of mealy bugs and plant lice. (H. S. P. A. Exp. Sta.)

CHAPTER IX

MORE TROUBLES IN THE FACTORY

Not all the troubles of the cane plant are caused by insects, for there are several diseases that make a lot of trouble, says Mr. Botanist, who has again taken up the story. Losses due to insect enemies now are not very great, thanks to Mr. Entomologist and the many beneficial insects which he has brought in here from foreign countries, but plant diseases sometimes cause serious losses and are harder to fight. Some of these are caused by microscopic parasites (fungi or in some cases bacteria), but some seem to be due to unfavorable conditions of the soil—as improper drainage, or the presence of too much of some kind of chemical substance in the soil. Some of the diseases are infectious, that is they spread from plant to plant, as certain infectious or contagious diseases of people may spread from one person to another. The diseases caused by soil troubles, however, are not infectious.

Mosaic or Yellow Stripe—Of the infectious diseases the worst is mosaic or yellow stripe, which is found in nearly all sugar cane countries and is the most feared of all cane diseases in the Western Hemisphere. It has been in the Hawaiian Islands for many years and is causing a considerable loss to the plantations by reducing the yield of sugar.

The disease makes itself known by the pale color of the leaves, often with blotches of lighter color which give the leaves a mottled appearance, or sometimes they are streaked with pale or yellow stripes.

The same symptoms may be found on sorghum, corn and several kinds of grasses which grow in and around the cane fields such as foxtail and crab-grass. From these plants, the sugar cane becomes infected with the disease, by the agency of a certain kind of insect.

This disease is infectious, but not by contact. It is spread by a small sap-sucking insect, the corn aphid, which usually feeds on corn but may also feed on sorghum or grasses which occur as weeds in cane fields, and occasionally it feeds on sugar cane. It is by the process of feeding of this corn aphid that the mosaic disease is spread, for its mouth is a long sucking tube by means of which the leaves are punctured and the sap sucked

out. When this happens on a diseased leaf, some of the disease "germs" are sucked out and then if the insect flies to a healthy sugar cane plant and pierces a leaf to suck out some more sap these "germs" are pretty sure to get into the healthy leaf and start the mosaic disease there.

The infectious agent is called a filtrable virus. It probably contains microscopic parasites, but they are so small that they cannot be seen with a microscope, and they will pass through a filter. It has been found that the disease is frequently started in sugar cane from corn, sorghum or foxtail as source of infection.

The aphid, however, is not to blame for all the spreading of this disease, for it has been shown by experiment that cuttings taken from a diseased cane plant will reproduce the disease in a large proportion of the germinations.

Varieties of sugar cane behave differently when attacked by mosaic disease. Some, like Lahaina and the Tip canes, are very susceptible to the disease and suffer severely. Others, as Demerara 1135, rarely become diseased. Still others, as Yellow Caledonia and Badila, are not often attacked but when the disease does gain entrance it causes much damage. Several (as Demerara 117, Uba Hybrid 11, and Kohala Seedling 202) seem to become easily infected but suffer very little actual damage from it. Uba cane is apparently wholly immune, but it is not a good commercial variety because of its low sugar content.

The easiest way to control mosaic is by planting a resistant variety, such as D 1135. In Porto Rico and South Africa the immune variety Uba is grown, but in some cases a resistant variety does not yield as much cane and sugar as a susceptible variety which is maintained free from the disease. In these islands the very susceptible Tip canes are sometimes grown, since under some conditions when free of mosaic they outyield any other varieties. When a susceptible variety is grown, measures to prevent the disease are essential since there are not known, as yet, any measures to bring about recovery of the cane once it is affected. Preventive measures are as follows:

- (1) Only seed cuttings from healthy cane should be planted. This is easily and cheaply accomplished by taking seed only from fields which are found to be entirely disease-free after inspection. Sometimes a few diseased stools may occur in a field and in such a case the inspector should top them so that seed would not be taken from such affected stools.

- (2) Young fields of cane should be inspected to observe any cases of mosaic disease and if diseased canes are found they should be dug out. Such eradication of diseased stools prevents

the spread of the disease to other cane, or into the grasses which occur as weeds in the field. It also makes the field disease-free for good seed cutting at maturity.

(3) In eradicating diseased stools a careful search should be made for grasses nearby which may have become affected, and such affected grasses, or preferably all grasses nearby, should be hoed out.

Eye-Spot Disease—Eye-spot is another infectious disease of sugar cane, prevalent in nearly every cane country in the world, but more destructive in some countries than in others. In Hawaii, it is most destructive on H-109 and Lahaina varieties and sometimes it causes a considerable loss.

The disease is called “eye-spot” because of the marks it makes on the cane leaves resembling an eye. A small oval area on the leaf, perhaps a quarter of an inch long, turns yellow, and as the spot gradually becomes larger a small reddish or brown spot develops in the middle which gives it the appearance of an eye. The two points of the oval spot then may lengthen out into a long brown streak which is very conspicuous.

The chief harm done by this disease is the killing of portions of the leaves, which reduces the ability of the leaves to make sugar. Badly affected leaves die completely and dry up much earlier than they should, and sometimes the disease may be bad enough to affect the very young leaves in the cane-top, causing them to rot, and then the entire stalk dies.

The cause of this disease is a parasitic fungus plant* growing inside the cane leaf. It consists of very slender microscopic threads which branch and rebranch and push their way among the cells of the cane leaf, robbing food from those cells and killing them, causing that portion of the leaf to become discolored as indicated above.

Instead of seeds which most plants form, this fungus plant forms myriads of microscopic spores. The thread branches which produce these spores always grow out to the surface of the cane leaf and the spores are thus developed on the free leaf surface where the wind will pick them up and scatter them far and wide. This is nature’s way of spreading this parasitic plant, for the spores are exceedingly tiny and light and are blown about by the slightest breeze.

Some of these spores, when blown about, may lodge on a cane leaf which does not have the eye-spot disease, but if the leaf is dry and the sun is shining brightly on it, the spores will not grow. However, if there is a little dew on the leaf and it is in

* The scientific name of this fungus parasite is *Cercospora sacchari*.

the shade, the spores may germinate and grow, sending out the tiny threads which penetrate into the cane leaf and so start a new "eye-spot."

For controlling or checking the eye-spot disease there are several things worth doing. Resistant varieties can be planted, such as D 1135, Yellow Caledonia, Badila, Rose Bamboo, Tip canes and Uba, but sometimes it is better to plant a non-resistant variety which yields more sugar, provided necessary protection against the disease is arranged for.

Protection, to some extent, can be had by not applying fertilizers late in the season, for fertilizers cause the growth of tender leaves which are more subject to the disease. Cutting out trees that shade the cane is a good protective measure. Poison dust (fungicide) is sometimes scattered over a plantation, to kill the spores before they penetrate the cane leaves.

Red Stripe Disease—Red Stripe is an infectious disease of sugar cane, caused by a certain kind of bacteria.* The disease makes itself known by red streaks or stripes on the cane leaves and the stunting or dwarfing of growth which results. Sometimes, also, the bacterial parasites attack the very young leaves in the cane top and cause a top-rot.

This disease is not at all general in Hawaii, being known thus far only on Kauai and in the Kohala district of Hawaii. By means of a rigid quarantine it is hoped to prevent the spread of this disease to other districts and to the other islands. The bacteria which cause this disease are microscopic in size and pearly white in color. They live inside the leaf, killing some of the leaf tissues by their presence and causing them to turn red.

The bacteria are blown about by the wind and splashed up from the ground by rain, but unless there is moisture and shade on the cane leaves they cannot gain entrance and cause the disease, for direct sunlight kills the bacteria and in the absence of moisture they remain inactive.

As a means of prevention, it is recommended to plant early in the season and fertilize early, so that when the rainy months of winter come the cane will not be in active growth and it will then be able to resist the disease better, for it is young cane (one to three feet high) and succulent growth that is most apt to be attacked by these parasitic bacteria.

Yellow Tip and Striped Tip varieties seem to be the most susceptible to this disease, while Yellow Caledonia, H 109, D 1135 and Badila and other varieties are resistant.

* *Phytophthora rubrilancea*.

Lahaina Disease—This disease in years gone by caused more destruction in these islands than any other plant trouble which has occurred here. At that time the Lahaina variety was the most widely grown, but when the disease became very bad other varieties were planted which are resistant to the disease. The variety mostly planted in place of the Lahaina is H 109, which is quite resistant.

The causes of this disease have never been well understood. It is now known, however, that Lahaina disease is not a single trouble but has two or three, or perhaps even more, distinct causes, each frequently operating alone in a different district but producing a more or less similar growth failure of the cane. One of the causes is thought to be the fungi that grow in the soil and sometimes attack the roots of the cane. One of these known as **Pythium**, was shown to be capable of considerably checking cane growth when present in the roots. Other causes may be various kinds of insects and other tiny creatures that live in the soil and often eat the cane roots or bore into them. A class of small worms, known as eel worms or **nematodes**, are particularly active in injuring roots and are probably to blame for some of the trouble.

Non-Infectious Diseases—There are several diseases of sugar cane which are not infectious and seem to be caused by something wrong in the soil. Correcting the soil trouble, if it can be discovered, "cures" the disease.

On the acid soils of these islands a growth failure of sugar cane is caused by too much soluble aluminum in the soil. Aluminum, when there is too much of it in the soil solution, acts as a poison instead of a food, and causes the cane plant to become stunted and slender-stalked and the leaves dry up sooner than they should. This type of injury was at one time considered identical with Lahaina disease. The "cure" for this type of Lahaina disease is to apply large amounts of potash fertilizers, the effect of which is to counteract the poisoning of the aluminum. This allows the cane plant to grow in a normal way and it recovers from the disease. Also, phosphate fertilizers or lime may be applied to the soil to correct the aluminum trouble, although this works more slowly than the potash.

A high salt content of the soil will make the plant sickly, and it is probable that such salt injury has been considered identical with Lahaina disease in some districts. The areas of high salt content are usual in regions of little rainfall and where slightly salty irrigation water is used.

Words to Remember

Aluminum—A chemical element which occurs in most soils and has some value as a plant food unless there is too much of it, when it may act as a poison to plants.

Bacteria—Exceedingly tiny organisms which live all about us, in the earth, water, air and practically everywhere; some are parasitic and cause diseases in animals and some in plants; they multiply by dividing into two parts and some kinds can live a long time in an unfavorable environment by drying up and becoming dormant or by forming spores.

Filtrable—Able to pass through a filter, therefore exceedingly small.

Fungi—Plants which do not have the green chlorophyll and therefore are unable to make food as other plants do; many of these fungi are parasites, robbing their food from other plants or sometimes from animals and thereby causing disease.

Fungicide—A liquid or dust which kills fungi, as sulfur or lime.

Immune—Free from and able to remain free from a disease.

Mosaic—A disease which causes a spotted, striped or streaked condition in leaves; this does not apply to plants which naturally produce such leaves, as Croton.

Nematode—A tiny worm usually less than 1/30th of an inch long, living in large numbers in the soil and sometimes damaging plant roots by piercing them and sucking out sap.

Spore—A simplified form of seed, very small (usually not visible to the naked eye) and different from a seed in not having an embryo plant inside as a seed has.

Virus—A poison liquid which is able to cause a disease when introduced into a healthy organism.

CHAPTER X

HARVEST TIME

For about a year and a half (15 to 20 months) after the young sugar cane began to grow Mr. Planter has watched its growth and protected it from harm and trouble so far as he was able, and now he comes to harvest time, in his story of sugar. It is a busy season and covers a much longer period of the time than the harvesting of most other crops, for Mr. Planter is occupied with this work for several months of the year, perhaps as much as 8 or 9 months.

The sugar cane plant has been compared to a factory in this story and it has been called a savings bank because the extra sugar which is not used up at once is put away in the stalk for future use. Now, Mr. Planter watches this factory work for more than a year and watches the savings bank increase, knowing that after a certain period of growth the factory will get no larger and the stored up sugar in the savings bank will after that begin to be used and it will get smaller and smaller. He can tell when this time comes by the tassels which grow at the end of the stalks when the plant is full-grown, and then he begins the harvest.

The best time to harvest is often determined by taking sample stalks in a field and testing them to find out how much sugar is stored up. If the percentage of sugar is good, harvesting of the whole field proceeds, otherwise it may be held up for awhile to let more sugar accumulate. The proper time to cut cane is when it has the greatest percentage of sugar (or sucrose). Usually the time to cut it is soon after the cane tassels or flowers. Within two or three months after this tasseling the sucrose will begin to diminish and there will be a loss in value.

The stalks have grown very long (8 to 15 feet) and being unable to stand erect they have bent over and become entangled with the nearby stalks to form a sort of jungle-like growth. This makes it very hard to come in with a harvesting machine and so the cutting is done by hand labor. First the leafy top of each stalk must be cut off because it has so little sugar in it that it is useless in the mill, but these tops are good for mules and horses and cows to eat, so they are not wasted. Then the stalk must be cut off as low down toward the ground as possible

because the richest part of the savings bank is the lower part of the stalk. The stalks are thrown into piles on the ground to be picked up and transported to the mill. Some people set fire to the field just before harvesting, in order to burn up the leaves and rubbish, the bare and leafless stalks remaining scorched but not burned after the fire has swept through the field. Mr. Planter says, however, that he does not "fire" his fields because it wastes too much organic material that ought to go back into the soil to save fertilizer.

This is the time to get the seed sticks for planting new fields, for the upper end of the stalk does not contain a great deal of sugar and can be cut off for seed without very much loss, and on that part of the stalk the eyes (buds) are better and grow more quickly when the seed stick is buried in the ground. Selecting the seed at this time is better, too, because it is possible to pick out the best fields and the best plants and take the seed sticks from them, for this is pretty sure to result in better sugar cane.

When the long stalks have been cut and thrown in piles another set of laborers come along to transport the cane to the mill. There are several ways of doing this. Mr. Planter lays long lines of portable railroad tracks into the field which is being harvested, and in this way he can haul the cane to the mill in freight cars pulled by a puffing locomotive. The cars are sometimes loaded by hand labor, the men walking up a sloping plank with an armful of stalks and dropping the load into the car, or sometimes the loading is done by a machine. A mechanical lift, or crane, takes hold of a large pile of cane on the ground, lifts it up and drops it into a freight car, accomplishing the work of loading much more rapidly than when it is done by hand labor.

These loaded cars now are pulled in a long train to the mill, where one at a time they are dumped and the cane dropped into the mouth of the mill. And there the story of the sugar mill begins.

Some of Mr. Planter's neighbors transport the cane to the mill in other ways. Some are situated on a long, gradually sloping mountain-side and instead of using trains they use over-head cables. A big bundle of stalks is tied together and hung on a trolley which runs on the over-head cable and gravity pulls the load down to the mill, or perhaps to a loading station where it drops into a freight car and then is pulled to the mill by a locomotive.

Still others use water as the transporting power, where there is an abundance of it and where the land slopes downward toward the mill. Wooden flumes are set up in the fields and the

water racing down carries the cane stalks down to the mill or to a way-station.

How much cane must be carried to the mill can be computed when the area of the field is known and the probable number of tons per acre. Mr. Planter says that in Hawaii the usual yield varies from forty to seventy tons of cane per acre, but some plantations produce a hundred tons per acre, while some drop as low as twenty-five or thirty tons if the conditions are not good. To transport seventy tons per acre from 5,000 acres is a big job, and that is what Mr. Planter must do.

Loading the cane cars in the fields is one of the heaviest jobs of all and therefore many attempts have been made to perfect a machine which would save this human labor, or at least reduce and lighten it. Cane loading machines are of various types. Some run on the same track that the cane cars use and others travel over the ground by the side of the track on "caterpillar" wheels. Most of them require that the cane be gathered in little bundles all over the field while the cane loader reaches out and picks up the bundles or drags them to the track and then lifts them into the cane car. A loader working on the principle of a hay loader has also been devised. All of these loaders require considerable man labor to operate them but not as strong men are required as in hand loading.

A successful harvesting machine is one of the things much desired and many efforts have been made to perfect a machine such perhaps as is used in harvesting grain crops, a machine which would cut and top the stalks and deliver the cane to the mill. On level fields such a machine will work pretty well and there are some in use in other sugar cane countries, but where the fields are not level and the ground is very irregular a machine cannot do the work well and may not be any cheaper than harvesting by hand.

Words to Remember

Crane—A mechanical lifting device resembling an arm.

Organic material—Dead leaves and other plant parts which become part of the soil, humus.

Percentage—A fraction expressed in hundredths; if sucrose constitutes 12 per cent of a cane stalk, or $12/100$, then 100 pounds of stalks would have 12 pounds of sucrose.

Trolley—A wheel and under-carriage rolling on a cable or wire overhead.

CHAPTER XI

THE SUGAR MILL

The story of sugar now turns from the open field to the huge mill where the sugary juice in the cane stalks is pressed out and made into **raw sugar**, and Mr. Mill Superintendent is taking up the story at this point.

Having followed the sugar cane in its growth from seed stick to mature cane, and having examined the plant itself, inside and outside, to learn about its structure and how it turns air and water into sugary sap and stores surplus sugar in the stalk, we may now go to the sugar mill and see how the sugar is removed from the stalk and manufactured into the sugar that people eat, says the new story-teller.

There are two things that have to be done to accomplish this. First, the stalks have to be crushed so that the sugary juice is squeezed out, and second, the juice has to be treated to separate and crystallize the sugar. The first is a mechanical problem and the second is largely applied chemistry.

A hundred years ago and earlier, people used to make sugar from sugar cane but they had very crude methods then, as compared to our modern ways. Big stone rollers, turned by oxen, were used to squeeze out the juice and this juice was simply boiled in a big open kettle until it became thick syrup. This syrup was then poured into molds where it would harden in big cakes of dark brown sugar. Pure sugar is clear and white, but this was very dark in color because it had in it "impurities" (other things which are not sugar). The modern sugar mill is a great improvement over these early crude methods.

The cane arrives at the mill as described by Mr. Planter, and is weighed so that the amount of sugar extracted from each ton of cane can be figured. Each car load is weighed and then it moves forward to the unloading machine. There are several kinds of unloading machines.

This machine takes the cane out of the cars and dumps it into a pit. In the bottom of this pit there is an endless belt or conveyor and the cane is picked up and carried by this to the huge rollers in the mill, which will press out the juice. On the way to the rollers, however, the cane passes under some knives which are whirling around very fast. This chops the cane into small pieces and prepares it for going through the rollers. One

set of knives is put half way up the conveyor, the other set is usually very near the top near the rollers.

As the cane reaches the top of the carrier it has passed through the knives and has been cut into small pieces. In this form it drops into the first set of big rollers, known as the **crusher** which is a pair of large, heavy cylinders turning on each other like a gigantic clothes wringer. These cylinders have sharp projections which break up the cane into smaller pieces, while the squeezing of these pieces between the rollers presses out a lot of the juice. This runs down to a trough under the crusher, where it is caught and conveyed to a big tank. Not all the juice is squeezed out in the crusher, however, and so there are more rollers to squeeze out the rest, but before this happens the cane goes to a shredding machine right after the crusher which breaks the pieces of cane into small bits. This machine, the **shredder**, consists of a lot of little hammers that fly up and down and beat into fine shreds the cane that has already been broken and pressed in the crusher.

From the crusher and the shredder, the stuff now goes to the second set of heavy rollers. This set consists of three rollers and presses the cane twice, squeezing out more juice but still not all. From this, the cane goes through a third set, also of three rollers and it may even go through a fourth set. Between these sets of rollers hot water is sprayed on the cane to wash out the sugar, for the water absorbs what little sugar may be sticking to the cane stuff and then the next set of rollers squeezes out the water and its sugar, leaving practically no sugar at all in the cane. This washing out of sugar with water between rollers is called **maceration** or **saturation**. You can illustrate this by saturating a sponge or cloth with sugar syrup and then squeezing it hard. This does not remove all the sugar, but if the sponge is again filled with clean water and squeezed and this process repeated several times there will be very little sugar left.

After the cane has passed through the series of rollers and has had practically all of its juice pressed out, the remaining stuff is a fibrous mass of shredded material which is called **bagasse**. There is always a small amount of sugar left in the bagasse, for it is impossible to get it all out. In a good mill, however, the amount left in the bagasse is very small, usually not more than 2 or 3 per cent of the sugar which was in the cane stalks as they entered the mill. If 2 per cent is left, the **extraction** is 98 per cent, and this is considered very good.

As the bagasse leaves the last of the rollers it is still wet, but it is conveyed directly to the furnaces which supply the steam power and there it is quickly dried out by the intense heat and

is burned up. Sometimes these furnaces are supplied with fuel oil to supplement the bagasse, but usually the bagasse is sufficient fuel to run the mill.

In Louisiana the bagasse is used for the manufacture of **celotex**, which is a good substitute for lumber for some building purposes; also, it is used in the making of fibre boxes for shipping freight. In this way it becomes more valuable than when used as fuel.

Now returning to the milling process, all the juice from the several sets of rollers is collected together as **mixed juice**. This is very dark in color because it contains a good deal of dirt and little particles of fibre which are left in it. These fine particles are known as **cush-cush**, and in spite of straining the juice through fine screens, a lot of it goes into the mixed juice.

The next step is to weigh the juice. This is done in large tanks which are mounted on scales.

The next step is clarification, which makes the juice clear. The common method is to treat the mixed juice, after it has been weighed, with milk of lime, which is lime and water in a mixture that looks like milk. The mixed juice is more or less acid and has to be neutralized, for otherwise the acid will make trouble when the juice is boiled down. Mr. Chemist tests the juice with litmus paper which tells whether or not it is too strongly acid. Then he adds the milk of lime which makes a cloudy appearance known as the **precipitate**. After the lime has been added, the juice goes into the juice heaters. These look like boilers and are full of little tubes through which the juice is forced back and forth very rapidly, for in this way it is heated by the steam which surrounds the tubes.

You can illustrate how this clarification is carried on by putting a little juice in a thin glass tube, and adding some milk of lime. Heat your tube of juice and lime a little over a flame and you will see that the heating of the juice and the lime together makes the juice get clear very quickly.

After the juice has gone through the juice heater, the next step is to allow it to settle for about an hour in large tanks, for then all the dirt and impurities go down to the bottom and form a layer of mud and sediment there, while above this layer is the clear juice and above the juice is a surface layer of scum and froth.

When the juice has settled for about an hour, the clear portion is drawn off. This is called **clarified juice**. The mud and scum remaining in the tank is removed into another tank for further treatment, for it still contains a small percentage of sugar and must be forced through filter presses to save this sugar. The mud finally left in the filter presses after this treat-

ment contains practically no sugar and is dumped into cars and sent out to the fields to be used as fertilizer.

The clear juice goes next into the **evaporators**. All the sugar in the juice is in solution and it must be transformed into solid or crystal form.

In the old days before they had modern machinery, they used to boil the juice in open kettles over a fire, until the sugar began to crystallize. But that is a wasteful method because you are likely to burn the sugar. Now, instead of using an open kettle they have a closed kettle known as the **evaporator**. The evaporator is nothing more than a great big kettle which can be closed air-tight and most of the air inside can be pumped out, leaving a partial vacuum. If you heat sugar in that kind of a kettle the sugar will boil at a lower temperature and there is not much danger of burning it. A little window or peep-hole is provided so that the operator can see the sugar boiling inside.

There are usually several evaporators in series, the juice passing from the first where it is partially concentrated by evaporating off some of the water, to the second and then the third and finally the fourth. In each successive evaporator a little more water is driven off, finally leaving a thick, dark-colored liquid that looks like molasses.

Next, this thick, dark syrup goes into another set of air-tight kettles, which are known as **vacuum pans**. These, like the evaporators, are closed and most of the air has been pumped out. The sugar is **made** (crystallized) in these pans. The vacuum pans are situated at the highest part of the mill, just under the roof, for it is very easy to pump the syrup up there, and the solid sugar which is made up there can be let down by its own weight to the floor below.

In the vacuum pans the thick syrup is boiled until crystals begin to form. The sugar boiler watches this operation very closely, for it must be stopped at the correct moment. He walks back and forth between the pans and looks into the little windows and looks at the vacuum gauge, which shows how much air has been pumped out. Every few minutes he takes out a sample of the sugar and puts it on a little glass and holds it up and looks through it. He tells by looking at the sugar crystals on the glass when it is the right time to stop boiling. At the proper time he turns off the steam, then lets the hot mass of material fall out of the pan. This mass is called **massecuite**. When the mass is allowed to fall out of the pan it is called **making a strike** or **dropping the pan**, which means that the massecuite has been brought to the right point to make sugar.

Massecuite is a mixture of sugar crystals and molasses and the next step is to separate the sugar from the molasses. In the old days they used to do this by letting the massecuite stand for a long time. By and by the molasses would drain away and the sugar crystals would remain behind. But this is a very poor way of getting the sugar crystals out. Now they use a better method, **centrifugal force**. You perhaps have tied a stone at the end of a string and have whirled it around and then let it go, and how the stone does fly! The force which pulls the stone away is called centrifugal force. We make use of that force in a centrifugal machine, which is a round box mounted on a spindle and capable of being rotated very rapidly, a thousand revolutions per minute. Inside the box is a smaller box with its walls made of fine mesh screen so that liquids may pass through, but the solid sugar crystals will be held back.

The massecuite is poured into the screen box inside the centrifugal. When the machine starts to whirl around, the sugary stuff is thrown against the screen wall and the liquid molasses goes through but the sugar crystals cannot, for the holes of the screen are too small. This separates the sugar from the molasses, the latter passing through the screen to the outer part of the whirling box, from where it is conducted into pipes and finally into tanks.

Some molasses clings to the sugar crystals in spite of the centrifugal force and must be dislodged by sprinkling a little water on the revolving mass. The water is forced through the crystal mass and carries some molasses with it. This is called **purging** or **curing** the sugar.

In making raw sugar not all the molasses is washed out, but the color of the sugar turns from very dark brown to a light brown color, as the centrifugal whirls and the molasses passes out, for it was the molasses that gave the massecuite the dark color.

When the sugar has taken on the right color, the centrifugal machine is stopped and a man lifts up a valve and takes a long stick and pushes the sugar down and it drops through a hole and falls into a bin. Some centrifugals have a little machine which helps to unload the sugar by pushing it down to the bottom.

If the sugar boiler has not been careful he may have allowed some little crystals to form in with the bigger sugar crystals, which is a very serious fault. They call that **false grain**. When the operator tries to separate these crystals from the molasses he has trouble because these tiny little crystals get into the screen and clog up the small holes and the molasses cannot get out.

From the centrifugal machine we have two products, sugar and molasses. The raw sugar, when it is dropped out of the centrifugal machine, is collected in some kind of a carrier which takes it up into the drying machine where it is partly dried. This machine is known as the **granulator**. It is a long cylinder and is turning around slowly as the sugar is being dropped into it from above, gradually working its way to the other end and drying as it goes. The sugar is dried in just the ordinary warm air that is found in the factory; no special heat is used, for the sugar might become sticky and make a hard lump in the bag. To prevent the sugar from caking or becoming hard they pass it through one of these drying machines, or granulators.

After this process is completed, the sugar is carried by a conveyor, usually an endless belt with buckets on it, which takes it to a bin and from the bin it passes down to the weighing machine, is weighed and then put in bags, each bag holding about 125 pounds. Then it passes to the sewing machine where the bags are sewed up. Then it goes onto the cars, which are sometimes waiting, or it may be put in the storehouse if there are no cars at hand. On the cars it is taken to Honolulu or some other shipping point and there it is put on board the steamer and shipped off to San Francisco.

The raw sugar that is shipped away contains about 97 per cent of sugar, or as we sometimes say, it is 97 degrees polarization, or 97 test sugar. That means that out of every 100 pounds of this raw sugar 97 pounds are real sugar and 3 pounds are something else, chiefly molasses.

Now, let us go back, to see what becomes of the molasses. When the sugar is purged or cured, the molasses is whirled off and is collected and runs down into a trough and is then stored in tanks.

This molasses contains quite a little sugar and it must be saved. This is done by putting the molasses back into the boiling process to cause the sugar to crystallize, just as the clarified juice was treated in the first place. They boil it with syrup and by and by they get another massecuite which is put through another series of centrifugal machines. Finally they get a molasses that is called **exhausted molasses**, for they have taken all the sugar out that they can get with profit, or have exhausted the molasses.

The exhausted molasses is used in several ways. Large quantities are shipped to the Pacific coast to be used as stock feed and some is used in that way here. In some mills a good deal of molasses is used for fuel by burning it in the great furnaces with bagasse or fuel oil to make steam. The ashes remaining make very good fertilizer, for there is a goodly percentage of

potash in it. Some molasses is made into fuel alcohol. Hawaiian molasses has a slightly bitter taste and is not used as a human food, as Louisiana or Cuban molasses is.

The Various Processes in Making Sugar

Weighing Cane.

Unloading Cane.

Cane Carrier or Conveyor.

Knives (one or two sets).

Crusher.

Shredder (sometimes).

Train of Mills (rollers in sets of 3 each).

Bagasse (used for fuel chiefly).

Maceration or Saturation.

Extraction.

Mixed Juice.

Weighing Mixed Juice.

Clarification of Mixed Juice	{	Addition of Lime.
		Heating.
		Settling.
		Filtering.

Clarified Juice.

Mud and Scums (the impurities and lime).

Clarified Juice goes to Evaporators.

From the Filter Presses	{	The clear juice-press juice goes to the
		Evaporators or back to clarification.
		The mud and scums go to the field as
		fertilizer.

Vacuum Pans or Pans for Boiling the Syrup to Sugar.

Masseccuite (mixture of sugar crystals and molasses).

Making a Strike or Dropping the Pan.

Centrifugal Machine or Centrifugals.

Purging or Curing of Sugar.

Drying Machine or Granulator.

Sugar Bin.

Weighing Machine.

Sugar Bags (each holds 125 lbs. of raw sugar).

Sewing Machine.

Storehouse or Cars.

Final or Exhausted Molasses (about 35% sugar).

Uses of Final Molasses	{	Mixed with cattle feed.
		Mixed with bagasse for fuel.
		Making alcohol for industrial purposes.

Words to Remember

Clarification—Making a cloudy or muddy liquid clear.

Extraction—Removing or separating the juice from the bagasse.

Filter press—A mechanical device for forcing muddy juice through cloth or other filter material to remove the particles which made the juice muddy.

Litmus paper—A special kind of paper which chemists use to determine whether a liquid is acid or alkaline.

Polarization—Testing the purity of sugar by means of a polariscope.

Precipitate—The particles of matter which settle to the bottom in a vessel containing a liquid.

Spindle—The axis on which a centrifugal machine revolves.

Vacuum—An empty space from which the air has been withdrawn; the extent to which the air has been withdrawn, or the degree of vacuum, is measured by a vacuum **gauge**.

Bagasse—The fibrous material left from sugar cane after squeezing out the juice.

CHAPTER XII

RAW SUGAR TO WHITE SUGAR

Raw cane sugar is light brown in color because there is a little molasses still adhering to the crystals, which not only makes it brown but also gives it a pronounced odor. Compared to the brown sugar of a century ago this modern raw sugar is very excellent, but people nowadays have become very particular in their eating habits and they want only the very best. The crude sugar of an earlier day does not satisfy them, and therefore the raw sugar must be made crystal white. So the story runs as told by Mr. Refiner, who is the superintendent of a great factory near San Francisco to which the raw sugar from Hawaii is shipped for refining into white sugar. This factory is called the California-Hawaiian Sugar Refinery.

The ships which carry the bags of raw sugar from Honolulu carry their loads over 2,000 miles of ocean to the big refinery where the sugar is discharged. As the bags of sugar leave the steamer and enter the refinery on mechanical conveyors they are first counted and weighed and then conveyed along to a table where a man cuts the stitches to open the bags and another man dumps the sugar through a grating into a big box or bin below.

From that bin the sugar is carried on conveyors up to the top floor where it is mixed with syrup and then sent through centrifugal machines, like those in the sugar mill already described. This process of mixing the sugar with syrup and **curing** it in the centrifugal machine is known as the **affination** process. The purpose of this is to wash out just as much of the molasses as possible, and when the sugar comes out it is known as **washed sugar**. It is now about 99 per cent pure sugar and 1 per cent molasses and other impurities.

After it has passed through the affination process, the sugar is dissolved into syrup and this is purified by filtering through what is known as a bone char filter. Bone char looks like small pieces of charcoal and is made from bones which are broken up in little pieces and heated in such a way that no air comes in contact with the bone, for when it is heated in that way it blackens and darkens but does not burn up. Bone char has wonderful power of taking the color out of sugar so that when

the dark syrup is made to pass through the bone char filters it comes out clear and white, having lost all its dark color.

These filters are big cylinders, sometimes twenty or thirty feet tall and about half as wide, filled up to the very top with bone char. The brown syrup goes in at the top and comes out underneath almost water white. They then boil that syrup in big vacuum pans and get a massecuite which is very light in color, which they put into centrifugal machines to separate the crystals from the liquid syrup. It comes out of the centrifugal machine a nice, white, crystalline sugar, made up of different sized crystals.

This must next be dried in a slowly revolving drier which is kept slightly warmed, and then the different sizes of crystals must be sorted out. This is done by means of a **bolting machine**, which consists of a series of sieves of different sized mesh through which the sugar is passed. The fine crystals are taken out first and each successive sieve will hold back the crystals next in size, thus separating the different sizes of crystals.

Cube sugar, also called "dominoes," is made by mixing some of the white, refined sugar with a little syrup, just enough to make a thick paste out of it and then a machine presses it in little molds just the size of the cubes. This machine, as it revolves, gently drops these cubes into a pan. If you should pick up one of these cubes at this stage, it would fall to pieces in your fingers, so they have to be baked just enough to make them hard. Crystal dominoes are made of very pure sugar,—almost 100 per cent pure.

From the domino machine or from the bolting machine the sugar comes out ready to be put into little boxes or perhaps into clean bags and shipped away for people to eat. Transcontinental trains pass by the big refinery and carry away this sweet freight for distribution far and wide.

Steps in Refining Raw Sugar

1. Arrival at Sugar Refinery.
2. Bags opened and dumped.
3. Affination process—raw sugar mixed with syrup, purged or cured in centrifugals.
4. Sugar dissolved in syrup.
5. Bone char filters.
6. White syrup, boiled down to white sugar.
7. Centrifugals to separate crystals.
8. Sifting to separate large and small crystals.
9. Pressing into cubes or dominoes.
10. Placing in bags or cartons for selling.

So the story is near its end, for the sweet juice made in nature's wonderful factory—the sugar cane plant—has been turned at last into white crystals of pure sugar, ready for your dinner table. The product of Hawaiian sunshine and air and water is now on its way, beautifully refined, to please millions of boys and girls all over the United States.

CHAPTER XIII

SOME HISTORY AND GEOGRAPHY

Our story of cane sugar should not be brought to a close without a glance back into history, for it has played an important part in some great world events, as the discovery of America, for example. To find a water route for the shipment of sugar and spices from India to Europe Vasco da Gama sailed around Africa, thus learning about that great continent, and Columbus set out on his memorable trip across the Atlantic which led to the discovery of America.

The first sugar, so far as we know, was made in India about 2,000 years ago, or perhaps earlier, and was a very rare delicacy used only at great feasts, and sometimes it was used as a medicine. Before that, people had not known how to extract the sugar from the plants that make and store it (as sugar cane and beets) and therefore had to obtain their sugar by eating sweet fruits and honey. The Greeks and Romans, in spite of their great advance in civilization, had not discovered the secret of making sugar, as the people of India did.

The Arabians, who were the traders of those ancient times, travelling in long camel trains between Europe and India, learned that sugar was made in India from sugar cane and carried some cane plants from there to the valley of the Tigris and Euphrates rivers where the stalks were planted and the making of sugar was begun nearer Europe. From there it was carried to Egypt and finally to Spain, but this required several hundred years, for progress moved very slowly then. Not until 1,200 years after the Arabians first learned about sugar in India did this sweet commodity become widely known in Europe, and it was the Crusade Wars that finally spread the knowledge of sugar far and wide. In England as late as the 14th Century sugar was a rare delicacy, costing 1 big pig for two pounds, or ten days' wages of a carpenter for the same amount.

In spite of the fact that sugar cane had been brought to Spain and Egypt the making of sugar there had not prospered and there was in the 14th Century a rapidly increasing trade in sugar between India and Europe, which was carried overland on the backs of camels. It was about this time that Columbus and Vasco da Gama made their discovery voyages which were

prompted by the desire to avoid the terrible dangers of the overland trips, for there were bands of robbers to beset the camel trains and other hardships and dangers along the way equally severe.

As soon as Europeans began settling in the new lands across the Atlantic they carried the sugar cane plant there and its cultivation became well established in Cuba and Haiti, then later in Mexico and Brazil. In 1751 the first sugar cane was grown in the American Colonies, but it was not of any importance until 1825, when in Louisiana it began to be a regular industry. From Mexico sugar cane was carried by the early Spanish traders and settlers to the Philippines and perhaps to Hawaii, more than a hundred and fifty years ago. Meanwhile, from India this sugar plant had been carried in the other direction to China before the 8th Century, A. D., and from there it probably was taken to the East Indies and the Philippine Islands and perhaps even to Hawaii before the Spaniards introduced it from Mexico.

Thus, in about 1,700 years this sugar-producing plant had been spread from India, going first to the west through Europe and across the Atlantic to the American continents and across the Pacific from there, and going to the east through China and meeting the other line of advancement in the Pacific Islands. And behind it as it travelled slowly around the world was a long story of wars, piracy and adventure as many new lands were colonized.

And with this story of slow progress around the world came an equally interesting mechanical progress upward from the crude methods of sugar extraction centuries ago to the remarkable machinery of the present day. During the 15th Century a citizen of Venice is said to have received a very large reward for inventing a way of making loaf sugar. The sticks of sugar cane in that early time were pounded with hammers to get the juice out, then came heavy stones tooled into cylindrical shape and rolled over a flat stone to press the cane. These were rolled by human power or perhaps by oxen or donkeys, and in some cases by water power. This method of pressing out the juice was in vogue the world around until a century ago or less. Then came the huge steel rollers, at first crude but rapidly improving to the modern type which extracts practically all the sugar that is in the cane.

Before the advent of the vacuum pan in 1858, the juice was boiled in open kettles until it reached the proper degree of thickness and then it was poured out into molds which allowed the molasses to slowly drain off, leaving a loaf of coarse brown sugar. The last 50 years has seen nearly all of the remarkable inventions in the manufacture of sugar in the modern mill.

Big Sugar Countries

Cuba is the largest producer of cane sugar, with an annual crop usually of about five million tons. Next comes India, the country which gave sugar to the world so long ago. Third in order is Java, with a crop of about two million tons. Many other countries in the tropical zone are important sugar producers. It is a good lesson in geography to locate the following countries on a world map. If you can find any statistics to show how many tons each produced last year it will be interesting to record the figures opposite the name of the country.

Cane Countries

	Harvesting Period
United States—	
Louisiana	Oct.-Jan.
Texas	Oct.-Jan.
Porto Rico	Jan.-June
Hawaiian Islands	Nov.-June
Virgin Islands, W. I.	Jan.-June
Cuba	Dec.-June
British West Indies—	
Trinidad	Jan.-June
Barbados	Jan.-June
Jamaica	Jan.-June
Antigua	Feb.-July
St. Kitts	Feb.-Aug.
French West Indies—	
Martinique	Jan.-July
Guadalupe	Jan.-July
San Domingo	Jan.-June
Haiti	Dec.-June
Mexico	Dec.-June
Central America—	
Guatemala	Jan.-June
South America—	
Demerara	Oct.-Dec. and May-June
Surinam	Oct.-Jan.
Venezuela	Oct.-June
Ecuador	Oct.-Feb.
Peru	Jan.-Dec.
Argentina	May-Nov.
Brazil	Oct.-Feb.

The Story of Cane Sugar

British India	Dec.-May
Java	May-Nov.
Formosa and Japan	Nov.-June
Philippine Islands	Nov.-June
Australia	June-Nov.
Fiji Islands	June-Nov.
Egypt	Jan.-June
Mauritius	Aug.-Jan.
Reunion	Aug.-Jan.
Natal	May-Oct.
Mozambique	May-Oct.
Europe—	
Spain	Dec.-June

Beet Countries

Europe—	
Germany	Sept.-Jan.
Czecho-Slovakia	Sept.-Jan.
Austria	Sept.-Jan.
Hungary	Sept.-Jan.
France	Sept.-Jan.
Belgium	Sept.-Jan.
Holland	Sept.-Jan.
Russia and Ukraine	Sept.-Jan.
Poland	Sept.-Jan.
Sweden	Sept.-Jan.
Denmark	Sept.-Jan.
Italy	Aug.-Oct.
Spain	Sept.-Jan.
Switzerland	Sept.-Jan.
Bulgaria	Sept.-Jan.
Roumania	Sept.-Jan.
England	Sept.-Jan.
United States—	
California	July-Jan.
Colorado	Aug.-Jan.
Utah	July-Jan.
Canada	Oct.-Dec.

In Hawaii

In Hawaii sugar has an interesting story to tell,* for it has been the chief factor in the development of this group of islands in the Pacific. Captain Cook, the discoverer of these islands, reports finding sugar cane growing in Hawaii in 1778, but the

* For a more extensive account of this story, read *The Story of Sugar in Hawaii*, published in 1926 by the Hawaiian Sugar Planters' Association.

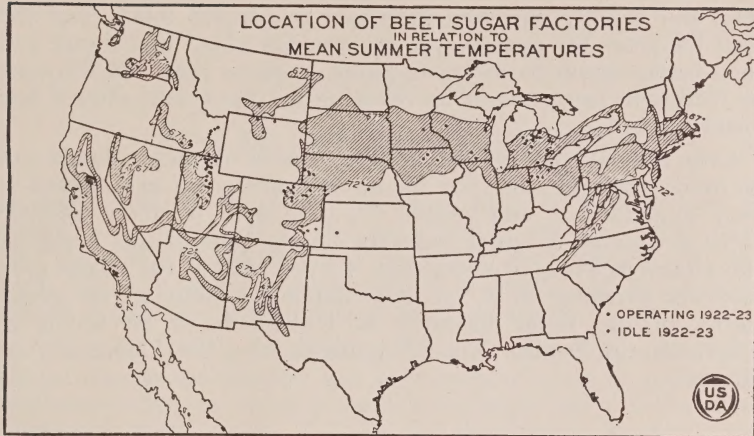


FIG. 32.—The sugar beet areas of the United States are shown in this map, in the darkened areas, with the dots representing factories. Wherever the summer temperature runs about 67 to 70 degrees F., sugar beets can be grown, if the soil is suitable. This figure was taken from the U. S. Department of Agriculture Yearbook, 1923.

Hawaiians did not make sugar from it, using it only in its raw state.

The growth of a sugar industry in the United States about 1825 caused some of the Americans in Hawaii to try it a few years later. In 1835 a field of 100 acres of sugar cane was planted near Honolulu but this project failed because of the high cost of labor—wages were only 25 cents per day! Other similar projects were successful, however, and a real industry was established, so that in 1837 there was exported from the Islands about \$300.00 worth of sugar, and by 1840 this had increased to about \$18,000 per year. Progress was very slow, however, for the methods were very crude and cumbersome and therefore expensive. When steam power came into use in 1858 the industry was greatly stimulated, but an even greater stimulus was the invention of the vacuum pan about that same time for boiling down the syrup. This did away with much of the crude work and the industry began to advance rapidly.

Then came the Civil War in America with high sugar prices to still further stimulate the new industry in Hawaii, and in 1876 the United States removed the tariff on Hawaiian sugar and admitted it free of duty, which caused the industry to leap forward in rapid progress. In 1900, when Hawaii had become a Territory of the United States, the sugar crop was 289,544

tons and in 1915 this had increased to 646,445 tons. For the next ten years the annual crop remained at about that figure and then began again to increase, going to more than 800,000 tons in 1928 with prospects of its reaching a million tons after a few years more.

Only a small part of the total land area of these islands can be used for sugar cane, for the central portion of each island is very mountainous and rough. A total area of about 240,000 acres is devoted to sugar cane, the largest part of this being on the Island of Hawaii where only 4.3 per cent of the island area has cane growing on it. A more detailed account of the geography of the sugar industry in Hawaii is to be found in "Agricultural Studies No. 2," published by the University of Hawaii.

CHAPTER XIV

SUGAR OF MANY KINDS

The people of the world eat more than 27 million tons of sugar in one year. If all this were put in standard sugar bags and these bags piled up into a heap 100 feet wide and 100 feet high, the heap would be twenty miles in length. That is a large pile of sugar, and it would be eaten in one year.

About two-thirds of this mountain of sugar is made from sugar cane in the tropical and near-tropical parts of the world, while the other one-third is made from sugar beets in the north temperate zone, chiefly Europe and the United States. Cane sugar and beet sugar are practically the same in every way, so that the temperate zone and the tropics are competing with each other for the world markets. Before the great war, the temperate zone produced nearly half of the world's sugar, but now the tropics have forged far ahead and sugar cane has become the world's greatest sugar plant.

Sugar beets are somewhat like our common garden beets, but much larger, often a foot in length, and instead of being blood red they are pale pink.

The process of manufacturing sugar from beets differs in some respects from that of cane sugar, especially in the first steps. The beets are first thoroughly washed and then sliced into small bits by machines. Instead of pressing out the juice by great rollers as is done for sugar cane, these slices are put in large tanks or vats where the sugar juice is soaked out in water. This sweet liquid then goes through a series of processes, as cane juice does—removing acids by adding lime and filtering to remove impurities, and then boiling down in vacuum pans to drive off the water and finally crystallizing out the sugar and driving off the molasses in centrifugal machines. The beet sugar mills do not produce raw sugar to be sent to refiners, but they make white refined sugar directly from beet juices.

There is left a large quantity of beet pulp from which the sugar has been soaked out, and this is dried and sold as stock feed, much of it coming to these islands to be used for feeding dairy cows.

Manufacture of beet sugar had its beginning in Europe in the first years of the preceding century, about 1810. About 1830 there was an attempt to grow sugar beets and make sugar in

Pennsylvania, but it was not successful, and no further efforts were made in the United States until 1869 when experiments in California proved so successful that the industry may be said to have started in this country then. By 1892 there were six mills in the West, mostly in California, and in 1913 there were 71 mills, while in 1920, 97 mills were in operation, turning out over one million tons of refined sugar.

When we have piled up all the cane and beet sugar into the 20-mile heap, we find that there are a number of other kinds of sugars to make the pile still larger. Several of these are of interest commercially, and deserve some part in this Story of Sugar:—

Maple sugar and syrup.
Molasses.
Sorghum syrup.
Honey.
Glucose.
Milk sugar.
Malt sugar.

Maple Sugar—If maple sugar were purified and crystallized in the same way that cane or beet sugar is treated, it would taste and look about the same as these, but we know that the common maple sugar of commerce tastes and looks very different from other sugar. The differences in taste and appearance are due to some other substances, impurities, which are not removed in the manufacturing process. It is these impurities that make it taste so good.

Maple sugar is made from the sap of maple trees, large and beautiful trees which grow in cold climates, as in the northern states of our country. This sap is obtained in somewhat the same way that rubber is gotten from rubber trees—by “tapping” the trees and allowing the sap to run out. Tapping the maple trees is done in the late winter and early spring months when the sap is moving through the tree trunks. Holes are made in the trunk of the tree, and as the sap runs out it is caught in pails hung for the purpose.

The sap, of course, contains the excess sugar which the trees made last summer and stored away in the savings bank for use in the winter and spring. Only a part of the sugary sap is taken in tapping the tree, for otherwise the tree would suffer starvation and would die.

The sap drawn out from the maple trees contains dissolved sugar, so that when it is placed in kettles and boiled down, the water evaporates and leaves the sugar in solid form. This is

molded into small "cakes" and sold in the stores. It could be purified, of course, and made into white, granulated sugar, but it would then not have its characteristic and very delightful flavor. To the boys and girls of the sugar maple states the "sugaring-off" parties are the most enjoyable occasions of all the year, for the making of maple sugar is not in elaborate mills where you are apt to be in the way, but it is done in out-of-door camps in the early spring, with all that that means in the way of sport.

People who eat these different kinds of sugars do not consider them all of the same value. Beet and cane sugars are generally about the same in price, but maple sugar is invariably higher because it is a specialty and also because of its delightful flavor. This, of course, leads some people to imitate the flavor and appearance by treating ordinary brown sugar, and so consumers sometimes have a false article sold to them under the name of maple sugar.

The production of maple sugar in the United States used to be much greater than it is now. In 1861 it amounted to about 40 million pounds, (20,000 short tons), but in the last few years the annual production has been only about 10 or 12 million pounds. Hawaii's production of cane sugar is several hundred times as great as that amount.

Maple syrup is just like maple sugar except that the juice is not boiled down to the point of crystallization. Some of the water in the sap or juice is driven off by boiling in open kettles, but before it reaches the sugaring stage it is taken off the fire and allowed to remain as a thick liquid. About 40 million gallons of the syrup are made and sold every year in the United States.

Molasses—Sugar cane juice as it is pressed out of the cane stalks contains two kinds of sugar—one can easily be crystallized and the other cannot so readily. The first kind is made into the cane sugar of commerce, but the other remains as molasses.

Molasses contains several things—some cane sugar that escaped being caught in the crystallizing process, some of the other kind of sugar, and some other substances that are usually called impurities as in maple sugar and maple syrup. These impurities are things that were in the sap of the cane plant and would have been used as plant food if we had not interfered by cutting and grinding the cane in the sugar mill.

Molasses made in various countries may have quite different flavors. Louisiana molasses has long had a good reputation as a food, being used in cooking and candy making. Immense quantities of it are sold every year.

Cane syrup, like maple syrup, is the juice or sap which has been boiled down to a thick syrup but not boiled long enough to cause it to sugar or crystallize. In ancient days a great deal of cane syrup was sold in the markets, but now in most sugar cane countries it is made into sugar.

In India, however, where perhaps there is a more extensive production of sugar cane than in any other country of the world, a very large part of the cane juice is made into syrup and sold in that form to the people of the country. The manufacture of sugar in India is rapidly increasing, but still the trade in cane syrup within that country is immense. It requires very little money to make cane syrup, for all you have to do is to press out the juice with large stone rollers, then boil the juice in big, open kettles until the desired degree of thickness is obtained. No expensive mills are needed, and for a country like India with its vast population of poor people, the cheap cane syrup has been more popular than the more expensive granulated sugar.

Sorghum Syrup—The Sorghum plant is a relative of sugar cane and corn, and is a member of the grass family. Sorghum produces a cluster of seeds in a tassel instead of an ear as maize or Indian corn does, and it is commonly called Egyptian corn. The plant looks very much like ordinary corn, except at harvest time, when its tassels of round plump seeds make it look quite distinct.

The stalks of some varieties of sorghum are good to chew because there is lots of sugar in the sap, as in sugar cane. These sweet varieties are cultivated for their sugar, but not so extensively now as before the advent of the modern cane and beet sugar industries. The stalks are crushed and the juices pressed out in roller mills, but instead of crystal sugar there is made from the juice a thick syrup, known as sorghum syrup.

The juice of the sorghum plant is sweet, but not so intensely sweet as cane juice. That is because a relatively large part of the juice is made up of that kind of sugar which does not readily crystallize (invert sugars), while cane juice has mostly the crystallizing kind of sugar which is more intensely sweet to the taste.

That explains, too, why they make syrup out of the sorghum juice, instead of granulated sugar, because there would be so much left as molasses if sugar should be crystallized out. The sorghum syrup is a light colored, thick, sweet syrup used extensively in candy making and cooking.

The industry in sorghum syrup may be said to have reached a climax back in 1880-1890, before the beet sugar industry had really made progress, and of course before the cane sugar industry had entered its modern development. In the period just

referred to, the United States produced about 25 to 30 million gallons of sorghum syrup per year—a large amount when one considers the smaller population of that time.

During the last decade of the preceding century, however, the beet and cane sugar industries made rapid strides forward and at the same time new and cheaper glucose syrups came on the market, and so the sorghum syrup business suffered a corresponding decline. The production dropped down to only a fraction of what it had been at its best. But in the last ten years it has been coming back, the annual production of 1920 having been nearly 50 million gallons.

The largest production of sorghum in the United States is in the southern and central states—Alabama, Mississippi, Kentucky, Arkansas and Georgia. Illinois, Ohio, Wisconsin and neighboring states produce some, but not as much as do the Gulf Coast states.

Honey—Honey was probably the first kind of sugar that people had to eat, and it is unlike the others we have been telling about in that it is prepared and stored up for us by other creatures—bees. Perhaps it is not quite correct to say that the bees prepare it and store it up for us, because it is wholly for themselves that they do it, but nevertheless men have helped themselves to honey stores diligently put away by the bees probably as far back in the world's history as there have been men. And, of course, men are not the only honey robbers, for bears and other four-footed creatures are known to have a sweet tooth, and do not mind a few stings from the outraged bees.

Honey is flower nectar, partly digested, from which some of the water has been allowed to evaporate to concentrate the sugar. Plants produce flowers for the purpose of forming seeds, and this requires the transfer of pollen from one flower to another. Now, usually it is by the agency of bees that the pollen is transferred and to attract bees, nature has developed two schemes—bright colors in the flowers and sweet nectar. The nectar is a sugary liquid which oozes into little pockets at the base of the flower, known as nectaries, the liquid being some of the sweet sap from the inside of the plant. This nectar is sipped up by Mrs. Bee (Mr. Bee is a loafer and never works) and then is carried home to the hive, where she places it in a wax cell. These cells of honeycomb are not covered up right away, but are left open to allow some of the water to evaporate so that the sugary liquid will be thicker. Then at the right time the cells are capped over with wax and the honey is in good storage for the winter.

Nectar of different kinds of flowers has different flavors, and, therefore, honey tastes and looks different according to what

flowers the bees visited. Most of our honey in Hawaii is from the algaroba or kiae flowers, and is light colored and delicious to eat. Some kinds of honey, however, are dark colored and not so good.

Nectar has two kinds of sugars in it, the kind that does not easily crystallize (invert or reducing sugars), and the kind that does, like cane sugar (sucrose). The first kind is always the most abundant in nectar, but sometimes it does granulate or turn solid.

Honey production has become a regular industry, with the colonies of bees treated as so much live stock. Bees used to live around in hollow trees and in any other place of refuge they could find, but now men keep them in hives of scientific construction, and by applying our knowledge of nature's laws of heredity, we have improved the bees so that they are more efficient as honey gatherers.

Many millions of pounds of honey are made every year in the United States and in other countries, as well. It is difficult to get exact figures on the production because so many people keep one or a few hives, the total of which is very large and can only be guessed at.

Honey usually sells a little higher than common white sugar, but its value goes up or down with the changes in the sugar market. Hawaii's production of honey is between 500 and 1,000 tons a year, most of which is exported to the mainland.

One interesting kind of honey which used to be very abundant here is that known as "honey-dew" honey. This kind was gathered and stored by bees, but not from flowers. It never was nectar, but instead was a sweet exudation from the bodies of the leaf hoppers that were so abundant on sugar cane plants. The bees used to gather this sweet liquid in large quantities when the cane leaf hopper was a bad pest here, but now they find very little of it. It is dark colored and tastes like molasses.

Glucose Syrups—The science of chemistry has added another kind of sugar to the list by turning starch into a kind of sugary syrup known as glucose. Starch is very much like sugar in chemical structure, and yet there is a big difference in taste and in other ways. But chemists have discovered a way to change starch into a kind of sugar, though it is not as sweet as cane sugar. This sugar, together with some of the intermediate products between starch and sugar, form water-white syrup of a sweet flavor, which is very valuable for candy making. In addition to this syrup there is made from starch a solid form of glucose sugar which is used by bakeries and candy manufacturers.

Malt Sugar—In some seeds the starch, which was stored there for food by the parent plant, undergoes certain changes when growth begins. The young seedling taking shape inside that seed cannot use the starch itself, so nature has provided a way of changing the starch into a kind of sugar, known as maltose or malt sugar, which can be used by the tiny, developing seedling plant.

When barley seed is kept moist the seeds swell and begin to grow. The process of "sprouting" or "germinating" causes the starch to change to malt sugar, hence the sprouted body is often called malt. (Remember the "malt that lay in the house that Jack built?") Now, if these sprouting seeds are killed just at the right time, the malt sugar remains there and can be extracted. Most commonly it is used in beer-making, this sugar being allowed to ferment by the action of yeast organisms which turn the malt sugar into alcohol. The malt sugar in the sprouted and killed seed may also be extracted for any other purpose, as it sometimes is for commercial use.

Milk Sugar—Cow's milk, as well as the milk of all animals, contains a little sugar. Ordinarily about 5 to 8 per cent of the milk is sugar in liquid form. This is extracted in some factories and changed into the solid form and then ground up into fine powder.

Milk sugar is made commercially only in very small quantities compared with the other sugars we have been discussing, and is used chiefly for babies and sick people, for it is easier to digest than common sugar. It costs about ten times as much as common white sugar.

By a newly devised method it is possible to make a solid sugar out of corn, very useful in the making of candy. This is called **maltose sugar**, and gives promise of becoming an important industry.

Another new source of sugar is indicated by laboratory experiments in which a very good confectionery sugar has been made from **artichoke** roots. This plant thrives in temperate zone regions and may become an important crop for sugar manufacture.

In discussing sugars, we should observe, too, that the saliva in a person's mouth has the ability of turning starch into a kind of sugar liquid, provided we chew the food long enough to allow the saliva to act. That is why we should chew our food thoroughly, to allow the saliva to do its work.

Other Sugars—All fruits have sugar in them, and sometimes this is extracted and sold in the form of fruit sugar or grape

sugar. Pineapples have a good deal of sugar which is used extensively at the big canneries. The juice is pressed out of the skins and cores and other parts which have not been canned, and this juice is put through a process similar to cane juice in the sugar mills, but instead of making granulated sugar they make a syrup which is mixed with cane sugar to sweeten the canned pineapple. A good many thousand gallons of pineapple sugar syrup are made in Hawaii every year and used directly in the canning processes instead of entering the usual channels of commerce.

Saccharin—Saccharin is in a class by itself, as a sweet substance. It really is not a sugar, although it is very sweet and is used in the place of sugar sometimes. It is so intensely sweet that one spoonful of it would be equal to 500 spoonfuls of ordinary white sugar. One tiny "pill" or pellet put in a cup of cocoa sweetens it as much as two spoonfuls of sugar. One part of saccharin to 10,000 parts of water make the water very sweet.

Saccharin is a white powder, composed, not of the three elements which make sugar, but of five elements—the same three plus two additional. Chemically, therefore, saccharin is quite different from the sugars.

Sugar, we have noted, is the product of plants. It is true we find sugar in milk and in blood, but it came there from the vegetable foods eaten. So we can say that sugar is always a product of the vegetable kingdom, although animals (which includes us) often change the form a little to make it different. Saccharin, however, is manufactured from coal tar. It is one of the many substances which chemists make from coal. Of course, we ought to observe that coal is a vegetable product, the remains of plants that lived on this earth millions of years ago, so that even saccharin, indirectly, is a product of the vegetable kingdom.

Saccharin is used by people afflicted with certain diseases which ordinary sugar aggravates, but its general use is not allowed by our laws because it is believed to cause some injury to our bodies. In countries where its use is not prohibited by law, saccharin is used for sweetening soda water and cheap drinks and in other ways as well. There are certain ways in which chemists can tell whether or not saccharin has been used instead of common sugar, so that it is dangerous to use this sugar substitute when it is against the law.

CHAPTER XV

THE SMALL PLANTER

Most of the sugar cane in Hawaii is grown on plantations of many thousand acres, each plantation having a sugar mill to manufacture the cane into sugar. Farming on such a large scale is really more of a manufacturing enterprise than agricultural, but of course it is based on agriculture. The manager of this large enterprise is familiar with agriculture and manufacturing and must also know about business methods, for his job is big business. Many people have invested their money in this enterprise and he must make a profit from his operations so that dividends can be paid to the investors, for they are partners in the business. It is as though a large number of small cane growers, each owning a few acres, would join together into a big partnership. Each one would give up his particular piece of land and take in its place a certain share in the whole enterprise and would share in the same proportion in the profits of the business. The big plantation is, thus, a partnership of many people and the manager must keep costs of production as low as possible so that the partners will get a good return on their investment.

In several parts of the Islands, however, there are many planters who grow small areas of sugar cane, perhaps five acres or sometimes thirty to sixty acres. These small planters usually depend upon the big plantation and its mill to buy and grind their cane, but in one place a number of them have banded together to form a partnership and have built a sugar mill of their own. The small planters often need to borrow money to pay for the cultivation of the cane before it is ready for harvest and in such cases the big plantation loans or "advances" some money which is to be paid back when the cane is sold.

When the small growers enter into this business they must have a market for their cane and so they make a **contract** with the mill company in which it is agreed that the mill will buy their cane, paying them a certain price per ton in proportion to the market price of sugar in New York. If the company has advanced or loaned money to them for the growing of the crop, this is deducted from the amount due them and also there is deducted the **interest** charged for making the loan, and then the remainder is paid to the small growers. If, for example, the

average price of raw sugar in New York during a certain month should be five cents per pound, then the small planter receives the corresponding price per ton for his cane fixed in the sliding scale. If the average sugar price is 4.5 cents per pound, then the planter receives a little less for his cane and if it is more than 5 cents he receives a higher price. Thus the planter shares with the mill company the risk of the uncertain sugar prices in New York.

In a few cases the contract between the mill company and the small planter provides a minimum price for the cane in order to protect the planter against loss if the sugar market should be too low. This is done by having the sliding scale begin with a price of 4 cents per pound for raw sugar. If the New York market falls below this price, such a contract would provide that the price for cane should not be lower than the price corresponding to 4 cents per pound for sugar.

The sliding scale arrangement usually works out so that when the small planter sells his cane to the mill company he receives for it about half of the amount for which the manufactured sugar is sold. This is based on the proposition that manufacturing, shipping and marketing the sugar costs about as much as growing the cane, and that the risks carried by the mill company are about as great as those carried by the planter. The mill company has a very large amount of money invested in the manufacturing plant, and both mill and planter are under great uncertainty as to the final results of marketing the crop in which both are partners in a certain sense.

There is another difficulty confronting the mill company in setting the price which it promises to pay for the cane brought to the mill by the small planters. The **quality ratio** or the amount of sugar which he can extract from a ton of cane varies a great deal. Sometimes eight or even seven tons of cane will make one ton of raw sugar, but sometimes it requires nine or ten tons of cane if the growing conditions have not been ideal. This cannot, of course, be determined in advance but varies from year to year and not all fields are alike in this regard. Some allowance, therefore, must be made for this variation and in some cases another sliding scale is provided in the contract, so that when the cane is richer in sugar the planter receives a higher price for each ton of cane, thus giving an incentive for proper irrigation and good fertilizing.

Homesteading

Thousands of small farms have been provided by the Territorial government of Hawaii for the benefit of people who wish to establish a farm home and make a living by growing sugar

cane, pineapples or other crops. These farms may be as large as eighty acres but usually are smaller, comprising perhaps twenty to forty acres. How much of a living a homesteader can make who grows sugar cane depends on several factors: (1) price of sugar, (2) yield of cane per acre, (3) cost of cane production, (4) size of farm, (5) kind of contract with the mill.

Over the price of sugar he has no control, as this is determined by world-wide forces of supply and demand. Over the other four factors, however, he does have a good deal of control and the amount of money he makes from his farm will, therefore, depend largely on himself.

How many tons of cane he harvests from his farm will depend very much on his methods of cultivation. Planting good seed and cultivating and fertilizing the plants well may bring, on an irrigated plantation, a harvest of sixty or eighty or a hundred tons of cane per acre, while careless methods and neglect in applying fertilizers or in controlling pests and diseases may result in a harvest of only thirty or forty tons of cane to each acre. On non-irrigated lands these figures would be considerably lower. It is plain, of course, that the profit of growing sugar cane on a homestead will be in the higher yields for the costs will not be correspondingly high and the cost per ton of cane will be less.

Costs of production must be kept down as low as possible, for the margin of profit on the crop is small, and the difference between profit and loss may be determined by the costs of production. An idea of these costs on one small cane farm may be obtained by reference to a bulletin published by the University of Hawaii (Agricultural Studies No. 7). On this farm of about 55 acres the cost of three crops (1923, 1925, 1927) averaged \$4.46 per ton of cane when ready for harvest and the harvesting costs averaged \$1.05 per ton. The average price received for this cane was \$6.31 per ton, making a net profit of 81 cents per ton, or \$26.28 per acre. This example is in the Waiakea district of Hawaii and is typical only of regions like that.

Other examples could be cited where the net profit was greater on each acre, and there are many farms where careless methods have brought poor yields and lower profits—perhaps no profit at all in some cases, even losses.

When the profit from a good homestead farm is augmented by some income from chickens, pigs or cows and perhaps a garden, it represents a moderately good income for a farm family, and a life of comparative freedom and independence with healthful conditions for a family in the country.

The government is very liberal in its plan of selling these farms to homesteaders, allowing the buyer a long time in which

to pay for the land and charging a very low rate of interest on the unpaid portion. This is done to encourage energetic young men to establish farm homes, thus developing a splendid type of American citizen which the country needs.

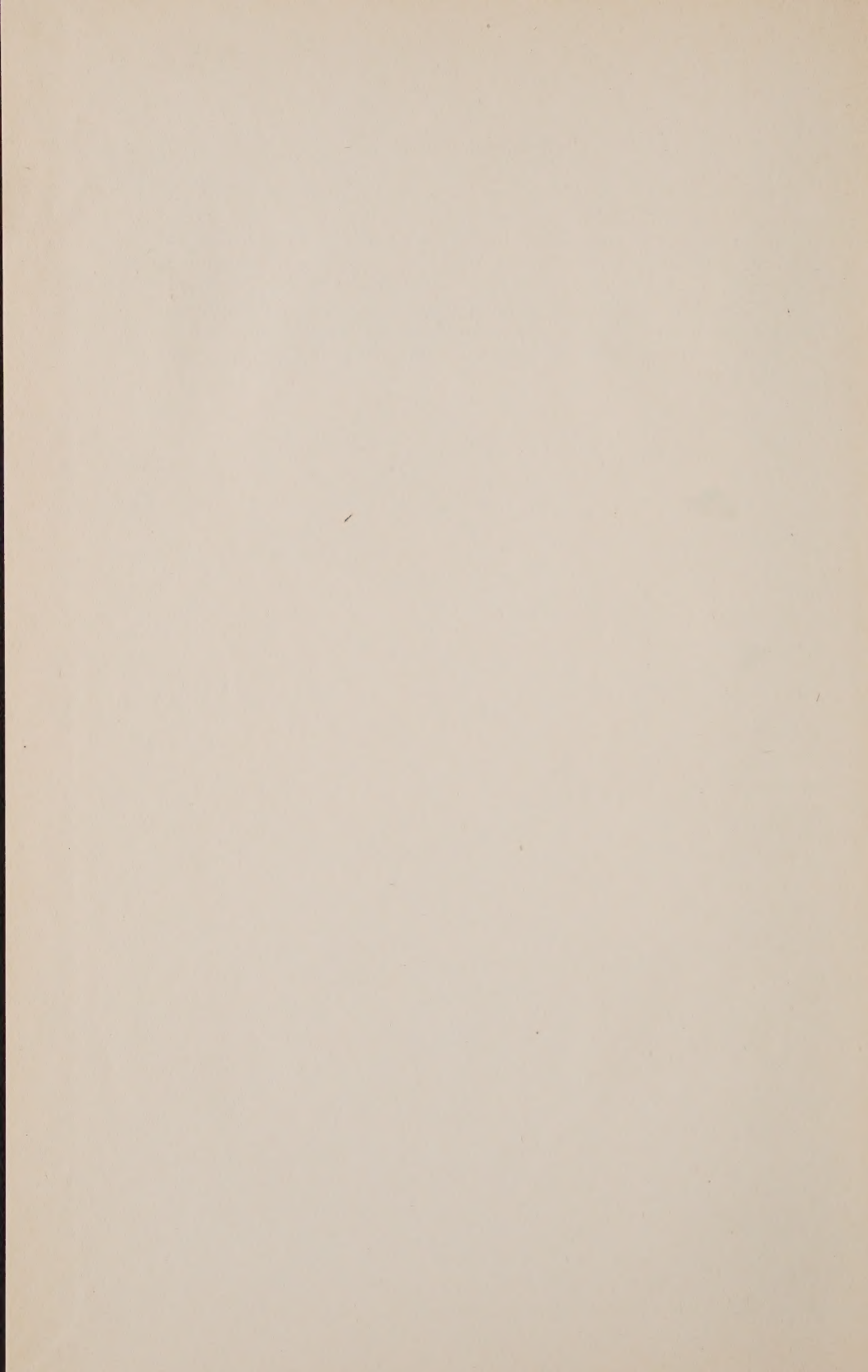
To earn enough money to buy one of these homestead farms it may be necessary for a young man to work for wages for a few years and put aside a part of his earnings in a savings bank. There are good opportunities to work on the plantations and not only earn money but learn about growing sugar cane. A man may work at a regular wage rate, or he may work on a contract basis, receiving a certain amount of pay for a certain job or piece of work. By this method, hard and intelligent work may result in much larger wages than the regular daily rate.

Cultivation Contracts

Still another plan which a well qualified man may follow is to enter into a cultivation contract with a plantation or mill company. By this arrangement, a man undertakes to care for a certain part of the plantation and is paid according to the amount of cane he raises on that piece of land. The price per ton which he will receive for this cane may be determined by a sliding scale similar to that used for homesteaders. The difference between this and homesteading is chiefly in the ownership of the land. The homesteader (if he is truly one) develops his own land, while the man on a cultivation contract works land that belongs to another. His profit will be as great as the homesteader's or perhaps larger, for he has the big company back of him to help in many ways.

Friendly cooperation is necessary between the mill companies and planters or cultivation contractors, for they are partners in a big business with many other sugar producing countries in competition against them. If either of the partners fails to do his part it means a lower efficiency and a corresponding advantage to the competing countries. This competition is so keen that it has become absolutely necessary for the production and manufacturing in Hawaii to be carried on in a large way for the sake of the greater efficiency secured thereby. This may be by means of huge corporations owning and operating large plantations and mills, or it may be by the gathering and banding together of a large number of small units to make a large enterprise, but in either case a high degree of cooperation is necessary between those who direct and those who perform the work. The banding together of many small planters offers more difficulties than the other plan, but when it can be done the enterprise should be profitable.

One may have the craving to own a farm of his own and he may do so through the homesteading method. Another, however, who wants an outdoor life and a chance to have a part in a big and important industry may care less about the actual ownership of a piece of land and will gladly identify himself with the big business of producing cane sugar, as an employee of a corporation or as a contractor working with a corporation. Each must see that his success and prosperity depends on cooperation.



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